TELEPHONY

A MANUAL OF THE
DESIGN, CONSTRUCTION, AND OPERATION
OF TELEPHONE EXCHANGES

IN SIX PARTS

PART III.

THE CONSTRUCTION OF CABLE PLANT

WITH 51 ILLUSTRATIONS

BY

ARTHUR VAUGHAN ABBOTT, C. E.

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McGRAW PUBLISHING COMPANY

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PREFACE.

BURIED beneath the surface of the streets the Telephone Cable attracts no attention; and few subscribers even reflect that a metallic thread, like a nerve, connects their instrument to the Central Station. Except to telephonists the cable is almost unknown, and it is not strange that during the past decade but little attention has been directed to this portion of the wire plant. There are symptoms now, however, of greater activity in circuit design. The rapidly increasing demand for telephone lines is congesting wire-ways so rapidly that in many cities it is difficult, and in some places impossible, to secure in the streets the necessary room in which to place the cable. Consequently cable builders are forced to increase the number of pairs of cable. From a transmission standpoint neither resistance nor electrostatic capacity should be augmented, and the cable designer is at his wits' end to devise a method whereby he may both eat his "cake and keep it." The inventions of Dr. Pupin point to a method of vastly improving transmission upon existing lines; reveal the ability to widely extend the territory that shall in the future be covered by cable service, and hint at the possibility of Ocean Telephony. The cable

portion of the wire plant, therefore, is at present one of the most interesting parts of a telephone installation.

In this volume the author has endeavored to collect such data as may be of service to the Telephone Engineer in the design and installation of the underground portion of the wire circuits, and to point out the principal direction which the probable trend in the design and manufacture of the cables of the future will take. As a large proportion of all cable is installed by the makers under contract and guarantee, a form of specifications has been framed, which it is hoped, with such modifications as time and place may suggest, may be found valuable in the prosecution of wire-plant building.

ARTHUR VAUGHAN ABBOTT.

NEW YORK, March, 1903.

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PART III.

TELEPHONY.

CHAPTER I.

THE PRINCIPLES OF CIRCUIT DESIGN.

Of all of the diverse parts of a telephone system, the conductors connecting the substations with the central office have recently received the least attention. Substation apparatus exhibits itself in a thousand forms, and each issue of the *Patent Office Gazette* adds to the number. Upon the switchboard and its appliances hosts of inventors have expended their skill, but the metallic road over which messages travel has remained for more than a decade almost unnoticed. As soon as the rapid multiplication of circuits pointed inevitably to underground lines the question of insulation became of paramount importance. The first expedient was to follow the lead of telegraph engineers and lay cables insulated with gutta percha or some of the rubber compounds. Such cables were expensive to install, and even more costly to maintain, as under the trying conditions of urban conduit service, the rubber soon deteriorated. Moreover, the transmission of speech was seriously impaired. Present

knowledge of the properties of electrical conductors is much clearer than in the early 80's. But even at that time it was recognized that the resistance of a conductor, and its electrostatic capacity, were important factors in speech transmission. The use of the smaller wire naturally employed in cables made an increase in resistance, while the rubber insulation and closer proximity of wires vastly augmented capacity. Observing this marked inferiority in speech transmission, Sir William Preece formulated his famous KR law, a proposition to the effect that unless the product of the capacity and resistance of a telephone line was less than a certain quantity (from 5,000 to 10,000 for open-wire circuits, and about 8,000 for cables) the line would not talk. Some lines on the continent of Europe and the first wires from New York to Chicago in the early 90's so built as to make this product greater than the assigned limiting values did talk, and talked fairly well; so the faith of electricians in the KR rule was shaken. Meanwhile, the invention of the Patterson cable placed in the hands of the telephonists a form of underground circuit at once so cheap, so durable, and so efficient that it is perhaps not strange that the cable problem was regarded as completely solved, and attention was directed to other fields.

While an extended exposition of the properties of electrical circuits is not only foreign to the scope of these papers, but from its necessarily mathematical character repugnant to the reader, it seems best to roughly sketch the governing factors in order that the principles of circuit design may be comprehended.

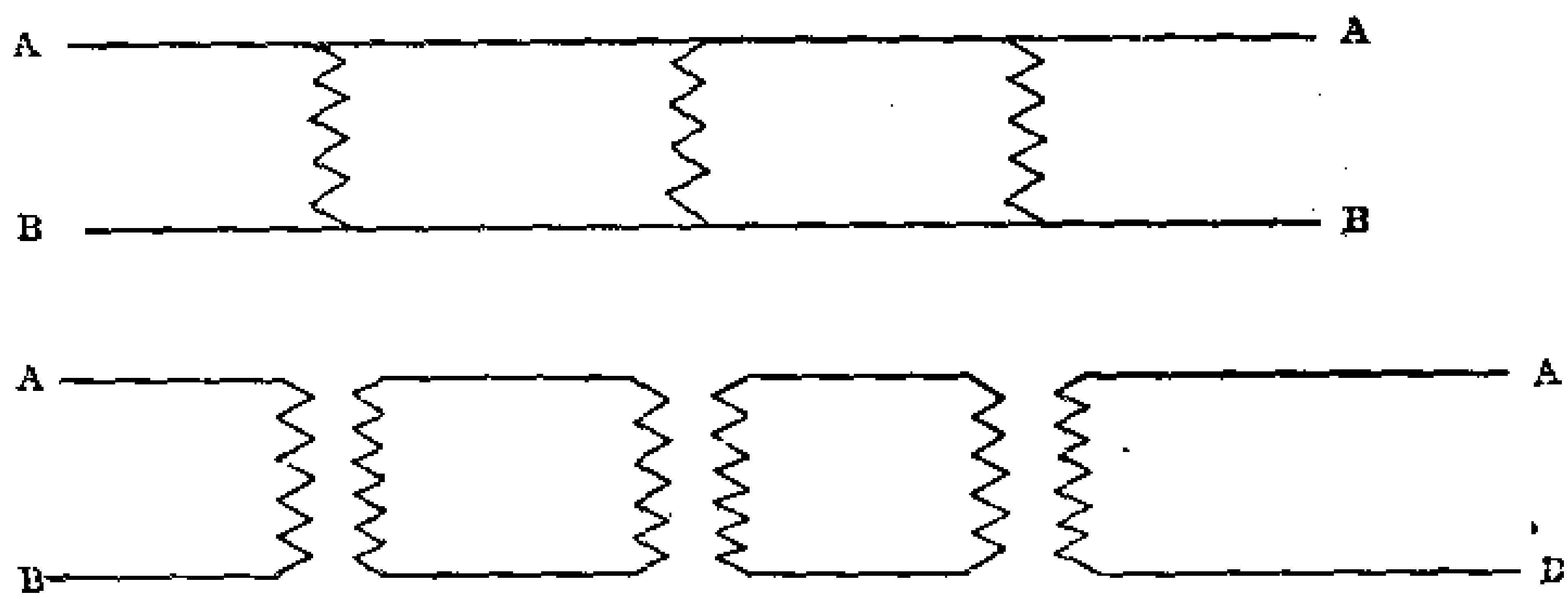
Imagine a force pump connected to a line of very elastic

hose. If the length of this pipe be very short, each stroke of the pump will be followed by a jet of water from the delivery end exactly corresponding in all respects, save a slight loss in energy due to the friction of the pipe walls, to the motion of the pump plunger. But if the hose be long all the conditions are changed. Before any water can be ejected from the remote end of the pipe, the inertia of the entire water column must be overcome, and if the strokes of the pump plunger be sharp and sudden the first effect is to distend the hose near the pump. The result is an increase in the quantity of water contained in the pipe, and the absorption of some of the energy delivered by the pump in the elastic reaction of the walls of the hose, and the water travels along the pipe as a wave, or pulse. If the pump strokes are very short and quick and the pipe large, long, and very elastic, it is conceivable that the character of the pump pulsations might be completely changed by the time they arrived at the delivery end, and the form of water jet transformed from a series of short, quick squirts to a flow more or less steady. In many respects electrical circuits behave in a similar manner, and in the design of telephone conductors, the length of the circuit is an important factor. If lines are of sufficient length, say something more than 15 or 20 miles, so that the energy transmitted as electricity is compelled to proceed as a series of waves, all of the laws pertaining to wave transmission will apply to, and must be recognized in the design of such circuits. If, on the contrary, lines are too short to permit the establishment of impulses, the laws of wave action need not be taken into account. In short lines the impulses impressed at one

end by the transmitter are received at the other end substantially unchanged in all of their characteristics save a slight energy loss occasioned by the ohmic resistance of the circuit, a quality analogous to the frictional resistance of the water pipe. Contrariwise, if the circuit be long, the energy transmitted proceeds as a series of waves, and under such circumstances the character of the impulses impressed by the transmitter may be completely changed by the action of the longer conductor. In order that articulation may be readily understood, and to enable one to recognize the voices of friends and acquaintances, the harmonics, or over tones, in which all speech abounds, must be clearly preserved, and it is these ripples upon the vocal sound waves, like the quick, short strokes of the pump that are easily obliterated by the elastic reactions of the electrical conductors over which they travel.

In the analogy, if by any means the elasticity of the pipe could be destroyed, then as the contained water column is inelastic, the strokes of the pump would be delivered at the receiving end unchanged in quantity and in quality. It was an attempt to recognize and to deal with this, at that time but dimly understood relationship, that caused Sir William Preece to formulate the KR law, indicating the impracticability of speech over lines in which the product of the frictional resistance and the elastic reaction exceeded a certain constant. In the hydraulic analogy, such a result would be obtained by substituting a rigid pipe, say, iron, for the rubber hose. Electricians have long known that electrical circuits possessed the property of inductance that was opposed to, and could be made to neutralize, capacity. More than a decade ago,

Mr. Heaviside showed mathematically that the addition of inductance to a telephone circuit in the shape of a wire coil should improve its talking properties, but when he attempted to carry out experimentally his mathematical deductions by inserting inductances concentrated at one or two points the results were disastrous, for lines which had talked passably prior to the introduction of the reactance coils, subsequently refused to transmit a syllable. In 1893, Dr. S. P. Thompson * in a paper entitled "Ocean Telephony," showed that as the capacity of a circuit was uniformly distributed along its entire length it was neces-



Figs. 1 and 2.—Correcting Inductances on Telephone Circuits.

sary to similarly distribute the correcting inductances, instead of concentrating them as Mr. Heaviside had done. Dr. Thompson showed two methods for using correcting coils; one plan is illustrated in Fig. 1, in which the coils are placed as shunts across the line at frequently recurring intervals. The other plan, Fig. 2, consisted in introducing transformers, thus splitting the line into a number of sections. As the perturbing action upon voice currents varies as the square of the length of the circuit, such fre-

* See Proceedings of the International Electrical Congress, page 143.

quent sub-division improves transmission by the simple process of cutting up a long circuit into a number of shorter ones, and by properly designing the transformers they may be made to balance out the capacity of line and act in the same manner as the inductive shunts. This effect Dr. Thompson's paper does not clearly specify, and while he showed a number of methods of building lines whereby their talking qualities may be improved no data is given as a basis for actual design. On December 12, 1893,* two patents were issued to Mr. C. J. Reed that embrace exactly the same features as are shown in Dr. Thompson's method. As Mr. Reed's applications were filed nearly a year prior to the International Congress, he must be regarded as a co-inventor or prior to Dr. Thompson. But Mr. Reed's patent gives no specifications as to building or using the transformers, and the language of the patent leaves some doubt as to whether he was fully aware of the possible effect of his invention on the talking properties of telephone circuits.

So it has been reserved for Dr. M. I. Pupin to prove both mathematically and experimentally the truth of the Heaviside theory, and to show that his practice was defective only in the design and location of the balancing inductances. Moreover, Dr. Pupin has gone a step farther than all prior inventors in accurately describing both the way to place the balancing inductance coils, as shown in Fig. 3, with reference to the waves transmitted by the circuit, and the design which should be adopted in their manufacture, in order to secure the best results. Those who are interested in this branch of the subject can do no

* See patents 510,612, dated December 12, 1893, 510,613 dated December 12, 1893.

better than to study carefully Dr. Pupin's papers before the American Institute of Electrical Engineers,* or to peruse his patents.†

Consider whether the hydraulic analogy will not explain the cause of Mr. Heaviside's failure. Suppose in

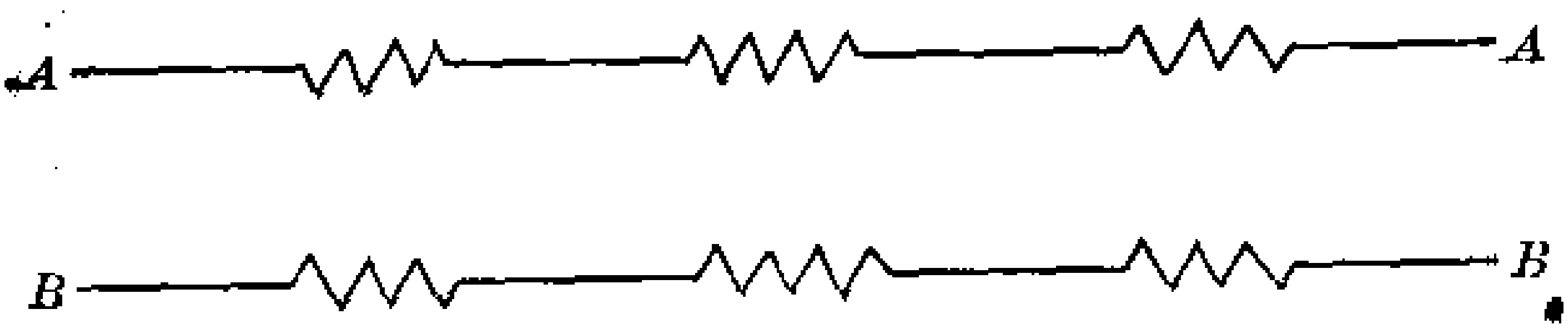


Fig. 3. — Correcting Inductances on Telephone Circuits.

order to counteract the elasticity of the hose one or two iron rings should be clamped about it. Doubtless these rings would have sufficient strength to confine all the energy imparted by the pump, but this restraining action would be restricted to their immediate vicinity, while the remaining and by far the greater portion of the pipe would still possess its original and undesirable elastic qualities. Now when a pump pulse travels along the pipe and reaches one of the confining rings, it cannot here distend the hose, and the wave is suddenly checked in its course, and a portion reflected back upon itself just as on the seashore the retiring breaker interferes with, and confuses the advancing wave. The confining ring thus not only fails to prevent the deformation of the pump pulse by destroying the elasticity of the hose at certain points, but it adds to the existing confusion by reflecting the water wave on itself and setting up interference waves. To the best of our present knowledge the Heaviside coils acted

* Trans. Am. Ins. Elec. Engs., Vol. xvi, 1899, p. 93 and Vol. xvii, 1900, p. 445.

† Patent No. 652,230, June 19, 1900, and No. 652,231, June 19, 1900.

in a similar manner, for while they tended to neutralize the capacity of the circuits in which they were placed, they were so located as to concentrate an excess of balancing action at one or two points, and instead of effecting an improvement set up a series of interference waves which added to the existing distortion. To return to the hydraulic analogy, if for the one or two heavy iron bands a large number of light wire hoops should be placed at frequent intervals along the entire length of the hose, the effect would be much the same as the substitution of a rigid material for the elastic walls of the hose, and the result at the receiving end would be jets of water co-ordinated with the pump strokes in shape and in time.

From this rough analysis it is seen that to properly design an electrical circuit one must regard its length in connection with the mutual relations of resistance inductance and capacity. If the circuit be shorter than the electrical wave length of the impulses it is called upon to transmit there will be no chance for true waves to be formed, and consequently the deforming action just described will not occur, and ordinary transmission in which ohmic resistance is a greater factor takes place. It is probable that voice impulses give rise to few important waves less than 15 miles in length, and consequently in dealing with shorter telephone circuits the effect of wave transmission may be neglected. But when it becomes necessary to consider toll lines running into scores, hundreds or thousands of miles the wave character of the transmission becomes the governing factor.

Subscribers' lines in the larger and telephonically denser cities will not exceed half a mile in length, and in the

smaller ones a mile or a mile and a quarter. But few trunk lines even in the largest exchanges are more than five or six miles long, so that in the design of single exchanges the question of wave transmission may be neglected, and circuits proportioned solely from the standpoint of resistance and capacity. Yet it must not be forgotten that as the telephone systems of the country develop, toll line communication will rapidly increase, and so the wire plant for each single office must be based on the probability that in the near future its circuits will be called upon to work in combination with toll lines which will be measured by hundreds of miles.

At present the use of balancing coils in long lines is still in the experimental stage, little or no extended practical experience having been gained therewith, while toward the improvement of transmission over underground cable little has been done beyond laboratory tests. That telephone circuits are soon likely to undergo considerable modification in design, which will result both in less expensive construction, and improved transmission seems certain, though it is difficult to forecast precisely the way in which such a result will arrive. There is no doubt of the wisdom of reducing resistance and capacity in all circuits to the lowest commercial limits, and this goal is to-day the aim of cable designers. The operation of resistance is to transform a portion of the electrical energy carried by the circuit into heat, which is radiated away, and, so far as speech transmission is involved, utterly lost. The amount of energy thus wasted is directly proportional to the square of the current, and the resistance of the conductor. Over conductors of high

resistance therefore speech transmission becomes *faint*, but the clearness of articulation is not impaired. Therefore to secure *loudness* in transmission large conductors of material of good conductivity must be employed.

The practical effect of capacity is to prevent successful transmission not so much by decreasing *loudness*, as by interfering with *distinctness*, thus b's and p's, s's and c's sound alike at the end of a high capacity line, and it is difficult to distinguish one word from another, causing frequent repetition. Capacity depends on the area of the conductors, their proximity to each other, and the character of the insulating material that separates them. The larger the wires of any circuit, and the nearer they are together, the greater the capacity. Air has about the lowest specific capacity of any known substance, so that the use of *any* other kind of insulating material necessarily increases capacity, thus the result of placing circuits in cables has a fourfold effect on transmission.

1st. The use of smaller wire increases resistance and decreases volume.

2d. The use of smaller wire decreases capacity and improves articulation.

3d. Twisting the circuits together brings the wires nearer to each other, increases capacity, and injures articulation.

4th. The necessary use of some insulating material besides air, increases capacity and injures articulation.

The net result is a perceptible decrease in volume when long lengths of cable are used, and a very marked impairment in distinctness, even over moderately long lines. The aim of the cable designed should therefore be:—

1st. To use the largest wire compatible with reasonable installation cost.

2d. To place the component parts of each circuit as far apart as possible.

3d. To use a minimum insulating material other than air.

The invention of the Patterson, paper, dry core, or air-spaced cable, as it is variously called, closely realizes

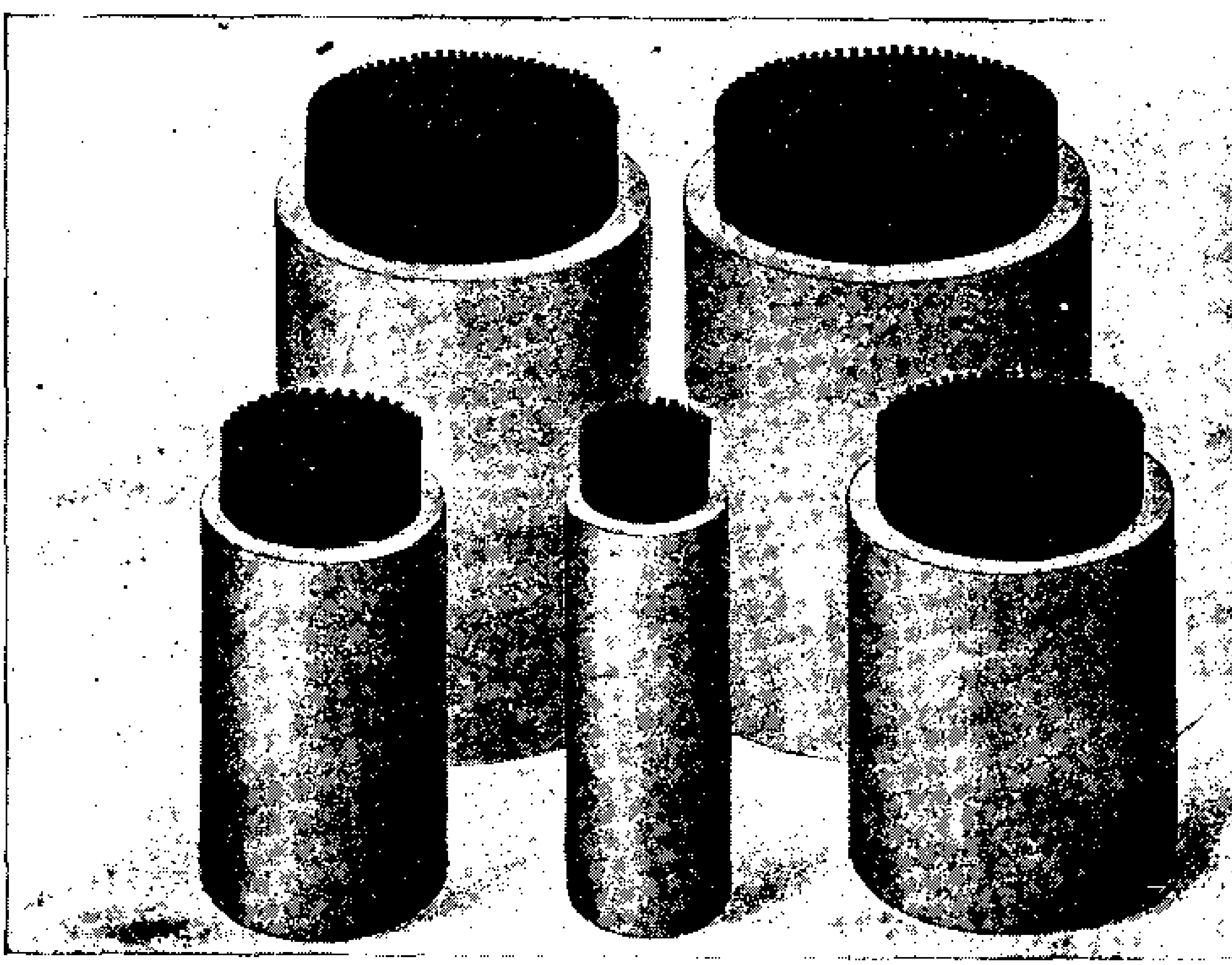


Fig. 4.—Paper-Insulated Cables.

these conditions. Several sizes of this cable are shown in Fig. 4. Copper wire of No. 19, B. & S. gauge, has been the usual size of the conductors. The requisite number of pairs to form the desired cable is taken, and each wire

insulated from its twin by a loose wrapping of carefully dried paper. It is customary to color in some distinguishing manner the paper on the individual wires in order to avoid the frequent testing otherwise necessary to distinguish the components of each one. One method of applying the paper is shown in Figs. 5 and 6, from which it is seen that the wires are simply separated by a sheet of paper, and then lightly twisted together, this twist being sufficient to hold both the conductors and the insulation in their proper relative positions, serving at the same time

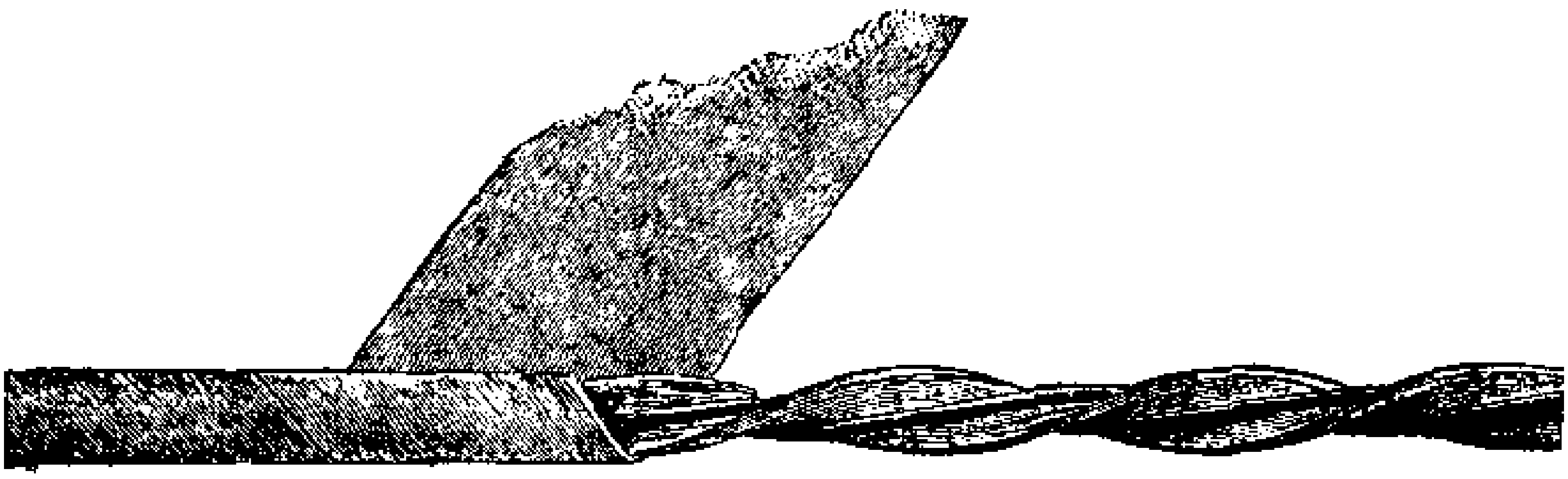


Fig. 5.—One Method of Applying Paper to Conductor.

the very important office of preventing cross-talk due to the mutual operation of electrostatic and electromagnetic induction. A single twisted pair is taken to form the core or nucleus of the completed cable, and around that the requisite number of pairs are assembled in regular layers, each successive layer being "cabled" or wound about the preceding one with a reversed twist, making a complete turn in from 18 inches to 36 inches. This process of "cabling" operates again to eliminate cross-talk between successive layers. The use of the paper to separate the individual wires furnishes an insulator of low electrostatic capacity, and yet of sufficient resistance

to maintain an insulation of many thousand megohms against the feeble electromotive forces of telephone currents. By twisting the various pairs of wire and the several layers very loosely about each other a considerable volume filled with air remains, and capacity is decreased by preserving as much space between conductor as possible.

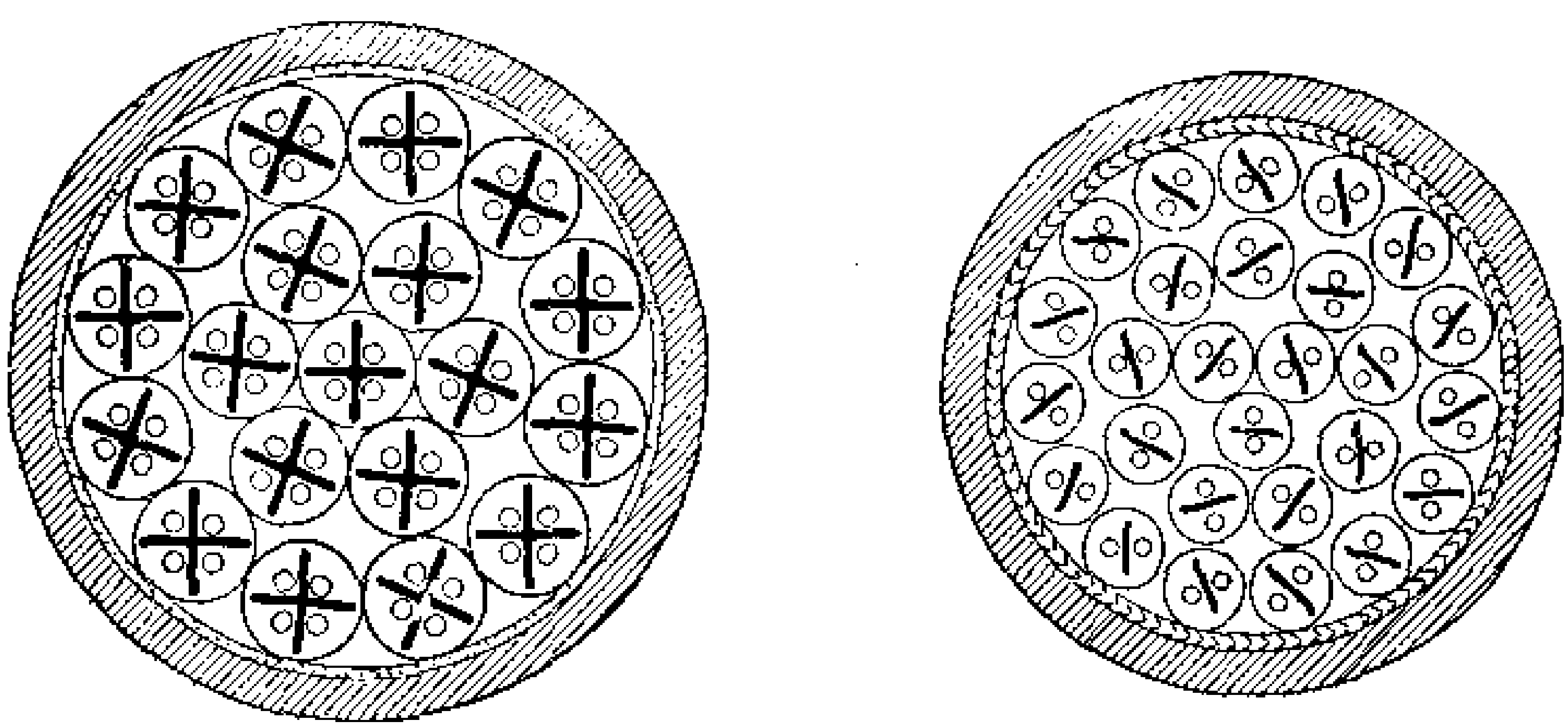


Fig. 6.—Cross-Sections of Paper-Insulated Cables.

To maintain such an arrangement of wires in working condition some protection is absolutely necessary, as the insulating material is not only hygroscopic to the last degree, and would retain its insulating properties for but a short time after being kiln dried, but is also of fragile character, and could not resist an infinitesimal amount of the handling needed to place circuits in their working position. Protection is achieved by inclosing the paper covered conductors in a lead pipe, which, if carefully made, is absolutely air tight, sufficiently flexible to be readily introduced into underground conduits or attached to pole lines, and indestructible under the corrosive influences usually encountered.

Not only must the successful cable talk well, but it must be reasonably easy and economical to manufacture, its mechanical attributes must meet the conditions of every-day service, and its design must be such as to make any desired rearrangements of circuits easy. About a dozen years ago the American Bell Telephone Company issued the famous "Conference Specifications," embracing the consensus of existing opinion as to the method of telephone cable building, and under which the bulk of all the telephone cable now in use has been constructed. The essential characteristics of the Conference Specifications are as follows:

Sizes. — Number of pairs, 25, 30, 50, 60, 100, 120.

Conductors. — Copper 19 B. & S. gauge, conductivity 98 per cent of pure copper.

Insulation. — Dry paper.

Conductor Arrangement. — Twisted pairs, length of twist not over 3 inches.

Core. — Laid up in successive reversed layers, with a lay of at least 1 turn in 2 feet.

Seal. — The end of each length sealed with insulating material for at least 2 feet.

Sheath. — The cores to be inclosed in a lead pipe $\frac{1}{8}$ inch thick, having at least $2\frac{2}{10}$ per cent of tin.

Electrostatic Capacity. — Shall not average more than .080 microfarads per mile.

Insulation. — 100 megohms per mile.

Guarantee. — Capacity shall not increase, nor insulation decrease, for five years.

The cables produced by these specifications so completely filled all requirements that it is only within the last two or three years that there have been any symptoms of departure from the good old Conference standard. But telephony is extending rapidly in both scope and quantity,

wire ways are becoming congested, competition is demanding greater economy in construction and better service to the subscriber, and it appears possible to introduce considerable economy in the cost of wire plant by building cables specifically adapted for the service demanded of them.

At the end of 1901 the approximate statistics for the telephone industry were as in Table No. I.:

TABLE No. I.

Telephone Statistics, Year of 1901.

No. of stations	2,300,000
No. of offices	6,500
Originating calls per day	12,500,000
Toll messages per day	275,000
Per cent toll messages to originating calls	2.2
Per cent trunk messages to originating calls	34.0
Total wire, miles	3,000,000
Aerial wire, miles	1,100,000
Cable wire, miles	1,900,000
Toll line wire, miles	260,000
Per cent trunk miles to subscriber, miles (when there is more than one office in an exchange)	30.00
Per cent of toll line wire to total wire	8.6

From the table it appears that the toll lines constitute only about 8.6 per cent of total telephone lines, and handle but 2.2 per cent of the total business. While doubtless this proportion will very rapidly increase, and the importance of toll traffic to general telephone business is fully realized, the advisability of designing subscribers' line, trunk lines and toll lines, each for its own particular sphere, is clearly shown. In 1898 or 1899 the 120-pair cable of No. 19 wire was the almost universal standard;

but the rapidly increasing congestion of wire ways is forcing more economical use of space, and 200- and even 400-pair cables have appeared. The standard 120-pair cable had a resistance per circuit mile of 94 ohms, and a capacity of .08 microfarads per mile. Experience has shown that commercial transmission can be carried on through something over 25 miles of such cable, or, in other words, acceptable service can be given through a line having a resistance of, say, 2,300 ohms, and a capacity of 2 microfarads. Any rearrangement of wire plant that does not interpose a greater resistance and capacity will, therefore, afford equal service. As subscribers' lines are short, more numerous, and comprise about two-thirds of exchange wire mileage, it would seem feasible to use cable of small wire, and consequently cheaper construction for this part of the wire plant; and for the trunk lines and toll lines install circuits of larger wire and better talking properties, thus securing good transmission and reducing installation cost. To illustrate: Compare the expense and electrical properties of two plants, one installed with standard 120-pair cable, and the other having 400-pair cable No. 22 wire for subscribers' lines, and 75-pair cable No. 18 wire for trunk line. The properties of such cables will be about as in Table No. II.

TABLE No. II.

Comparison of Cable Plants.

No. of pair	75	120	400
Size of Conductor B. & S.	17	19	22
Resistance per circuit mile in cable ohms	59	94	187
Capacity per mile Mf.	.065	.080	.120
Cost per active pair mile	$83.00	$52.00	$21.00

To compare probable transmission assume an exchange where the telephonic density is such as to make the average subscribers' distance from the office half a mile, and the average trunk-line length five miles. Such conditions now represent about the average of the larger cities. Then a comparison between the two plants will be as in Table No. III.

TABLE No. III.

Comparison of Electrical Properties of Wire Plants Built with Cables as in Table No. II.

	120-Pair Cable.	75- and 400-Pair Cable.	Per Cent. Change.
Resistance of two subscribers' lines in the same office . . .	94 Ohms	187 Ohms	199.5
Capacity of two subscribers' lines in the same office . . .	.080 Mfs	.120 Mfs.	150.
Resistance of two subscribers' lines in different offices . .	564 Ohms	482 Ohms	85.5
Capacity	.480 Mfs.	.445 Mfs	92.
Cost	1	.695	69.5

By the preceding table it is clearly shown that the 400-pair cable will *not* give as good transmission between subscribers talking in the same office as a No. 19 wire cable will. But as the total resistance and capacity of two such wires is very small, a reasonable increase in the objectionable electrical properties is unnoticeable, as the permissible margin is *very large*. Passing to trunk-line conversations, it is shown that the combination of the 400-pair No. 22

wire cable and 75-pair No. 17 wire cable decrease resistance to 85.50 per cent of the No. 19 120-pair plant capacity to 92 per cent, and *cost* to 69.5 per cent. This is an attractive showing.

Conduits as now built readily take a $2\frac{1}{2}$-inch diameter cable, and possibly one $2\frac{3}{4}$-inch; so by existing construction cables sizes are now limited to the preceding dimensions, and design must accommodate itself thereto. In a general way it appears desirable to have about seven varieties of cable for subscribers' lines, and about three varieties for toll- and trunk-line service. Table No. IV. gives the approximate general properties suggested.

TABLE No. IV.

Cable Data.

Purpose.	No. Pairs.	Size of Wire.	Capacity per Mile.
Subscribers' lines distributing cable	10	19	.085
Subscribers' lines distributing cable	30	19	.085
Subscribers' lines distributing cable	50	19	.085
Subscribers' lines, main and distributing cable	100	19	.085
Subscribers' lines main cable	200	20	.110
Subscribers' lines main cable	300	20	.115
Subscribers' lines main cable	400	22	.120
Subscribers' lines main cable	600	24	.140
Trunk line cable	75	17	.065
Toll line cable	50	14	.050
Toll line cable	10	10	.035

With the selection outlined it would seem possible to so adjust cable design under all usual circumstances as to attain good service at a minimum cost.

CHAPTER II.

MECHANICAL PROPERTIES.

ONLY the electrical properties of cables have so far received attention, but certain mechanical characteristics are essential to permit of installation and to preserve the cable in working order. The integrity of the cable depends on the integrity of the sheath, which must be of sufficient strength to withstand without rupture all the manipulation necessary to transportation and erection.

The thickness of the lead sheath varies slightly with different makers, but experience has shown that for 25 pair and less, 1-16 inch is sufficient, from 25 pair to 50 pair 5-64 inch, from 50 pair to 150 pair 3-32 inch, and over 150 pair ⅛ inch. To economize weight aerial cables are usually made of slightly thinner sheath than underground, and of No. 20 gauge instead of No. 19.

Early cables were supplied with sheaths of pure lead, but frequent corrosion was experienced, to obviate which an alloy of about 3 per cent tin was substituted, or a subsequent wash of pure tin was applied, after the wire was inclosed in the pipe, by drawing the completed cable through a bath of melted tin. Of the two processes, the lead-tin alloy yields the most desirable results in the ducts, though with it is somewhat more difficult to secure

a sheath absolutely free from pinholes and cracks. The addition of the tin has been found so beneficial that little cable is now made without it. Cable of No. 19 gauge is somewhat easier to splice than that made of smaller wire, chiefly because there has been much experience with this size, and cable makers know exactly how to handle it, so with small gauges greater care must be exercised till more experience is gained. The strength of the cable is limited to that of the lead pipe, for the loose core of paper-covered wire possesses no resistance in any direction. Much care is therefore essential in handling so fragile a structure as a 2½-inch lead pipe, ⅛ inch in thickness, and several hundred feet in length. When placed on reels if too long lengths are used the inner layers are crushed by the weight or tension of the exterior ones. A sudden or sharp bend will produce a kink in the sheath that flattens the contained circuits together, and is likely to rupture the paper and produce a lot of "shorts," or even may develop a crack in the lead that will pass undetected until the entrance of moisture causes the entire cable to utterly fail.

In erecting cable, either aerial or underground, the cable should be drawn off the reel directly into place, and not pulled over rough pavements or gravelly roads, where injury to the sheath is almost inevitable. It is claimed that the sheath of cable so placed as to be exposed to constant vibration (on bridges, for example) will gradually crystallize and rapidly deteriorate to a point of no longer affording protection to the circuits. As most instances of this nature when carefully analyzed are found due to defect in original materials, or workmanship in manufac-

turing, little apprehension on this score need be entertained under all ordinary circumstances.

SPLICES AND TERMINALS.

Owing to the hygroscopic and fragile character of the paper insulation, special care must be observed in terminating and joining cables, in order to keep the main body moistureless. Each piece of cable as delivered by the manufacturers has some 3 feet or 4 feet of each end boiled in paraffine, after which the lead of the sheath is turned over and soldered; in this condition the cable will keep indefinitely. When two pieces are to be joined the sheath is stripped away from each end for 18 inches or 2 feet. Then a piece of lead pipe an inch or 1½-inch larger than the cable and about 2 feet long is slipped onto one of the cables. The paper from individual wires is then stripped off, and each wire in one cable twisted to its proper mate in the other, the wire joint being protected by a paper sleeve. When all the pairs are then connected the lead sleeve is slipped over the splice and one end "wiped" onto the sheath of one piece of cable, the splice is then "boiled" out by being immersed in boiling paraffine for some little time, after which the remaining end of the sleeve is wiped onto the sheath of the other cable and the splice is complete. Full details of this method will be found under the head of "*Specification for Cable Splices.*"

Cable Heads.—The termination of the cable is a much more difficult matter in order to secure complete immunity from moisture, for here the individual wires must be brought out in such a way as to be utilized in any desired

manner. There are two general types of terminals — *The Cable Head* and *the Pot Head.* The cable head consists of some sort of an air-tight box, or receptacle, to which the sheath of the cable may be soldered, and inside of which the circuits may be fanned out and attached to pins or studs extending through the sides of the box, thus affording exterior connections to each cable wire. After the cable sheath is attached to the head and the wires connected to the terminals the head is sealed up.

The Pot Head method consists in splicing onto the paper cable an auxiliary cable, long or short, as circumstance may indicate, made of wire insulated with some non-hygroscopic material (say, rubber), and covering the joint with a lead sleeve, wiped onto the cable sheath, which is subsequently filled with a rubber compound such as Chatterton's. The cable head is the older plan, somewhat easier to successfully install, has the advantage of affording an excellent opportunity to test circuits, and lends itself to the easy attachment of protectors; but takes up a great deal more room, and is much more expensive. The cable head presents itself in a legion of different forms. The plain head or one unequipped with protectors, Fig. 7, is most usually made as a rectangular iron box about 6 inches or 8 inches wide by 4 inches or 5 inches deep, and of varying lengths sufficient to accommodate the different sizes of cable. In one end a piece of brass pipe is threaded, to which the cables heath is to be soldered, and through which the cable pairs pass to the interior of the head. Along the two opposite sides a series of insulated pins (often in the form of binding posts or supplied with a pair of threaded washers) corresponding to the number of

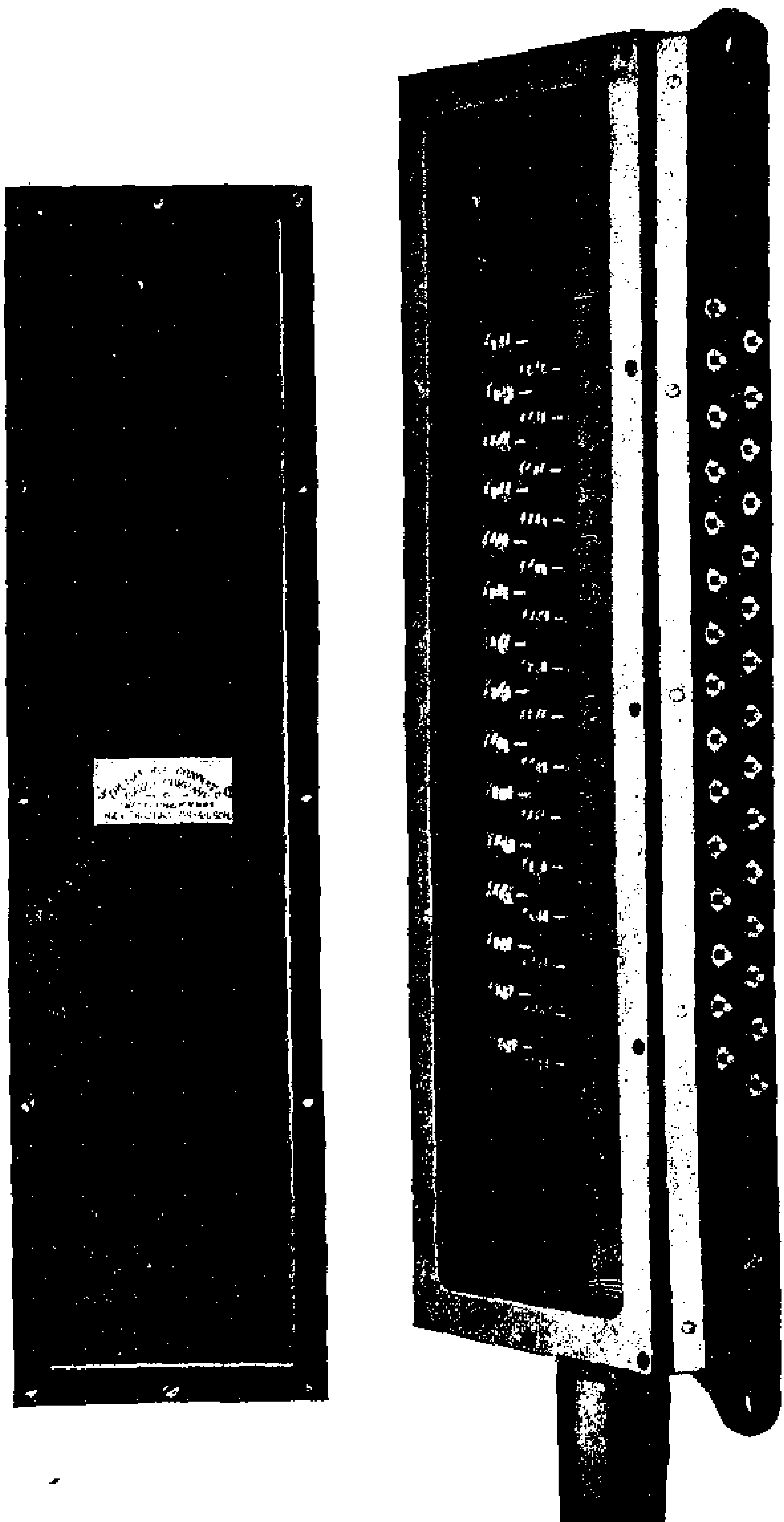


Fig. 7.—Plain Cable Head.

cable wires are placed, to which, on the inside, the cable pairs are soldered, and from which on the outside the circuits are extended. One face of the head is in the form of a cover supplied with rather heavy bolts to draw it firmly against a rubber gasket making an air-tight joint. A very neat and compact, though somewhat expensive design, as it is made of rubber, is shown in Fig. 8, also illustrating the cable in place. Fig. 9 shows a cable head supplied with protectors, each line having a set of carbon plates and fuses, suitable for an office terminal in connection with an unprotected distributing board. Modern practice, however, strongly tends toward making the cable endings in central offices as simple as possible, and concentrates all protection on the main distributing board.

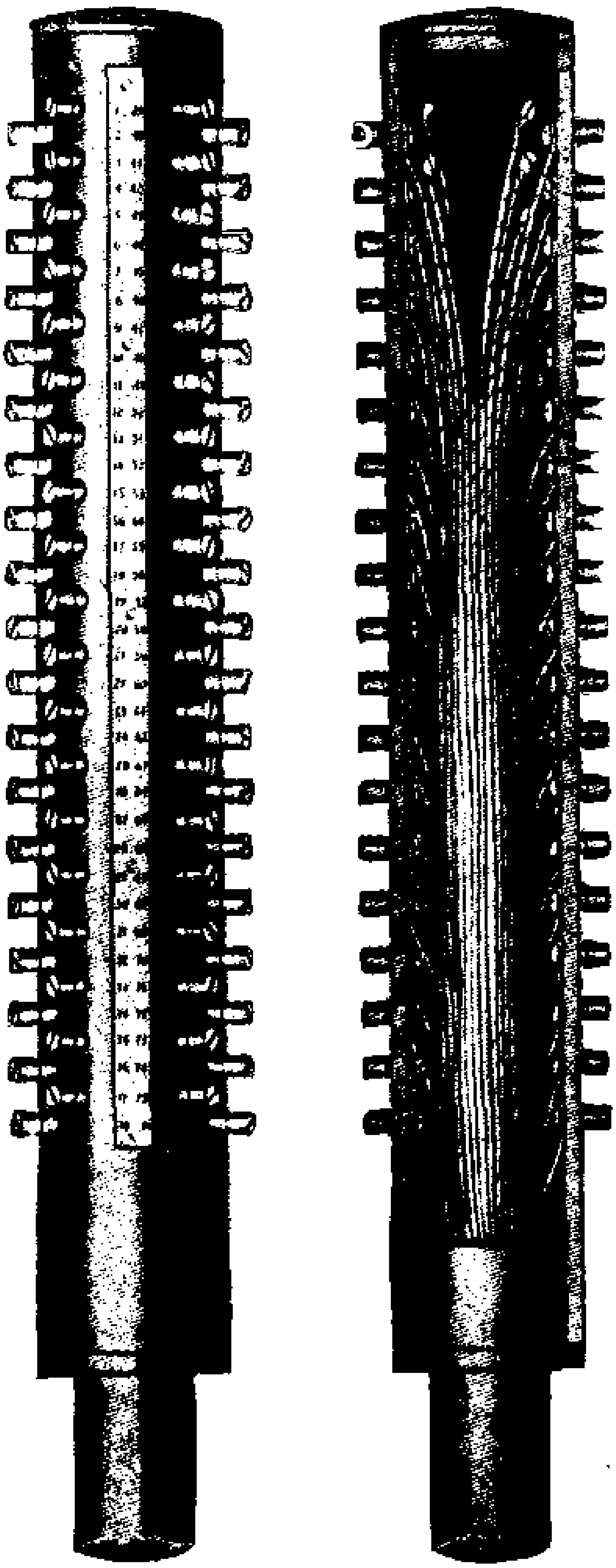


Fig. 8. — Cable Head.

Where cables run into open wire lines the head must be placed on the line poles as close as possible to the cross-arms, and the pins of the head connected to the open wires of the aerial lines by short lengths of rubber-covered wire, called "bridle-wires" or "jumpers." It is usual to inclose the head in a box provided with doors, to protect it from the weather, and house the fuses and lightning arresters that must be inserted between the cable head and the open wire to guard the former from atmospheric electricity, and accidental crosses with other electric wires. To facilitate the duties of linemen, a platform or "balcony," as it is technically termed, is built just below the cable head. The general method of connecting cable and open-wire lines as represented by examples in good practices, is shown in Figs. 10 and 11, showing a neat and orderly arrangement of circuits, and two varieties of cable boxes. In Fig. 11 the forms of rubber jumper wire connecting the cable to the open wire are seen extending on either side of the cross-arms. Fig. 12 is the type of construction usually found in middle-sized towns, and is an ex-

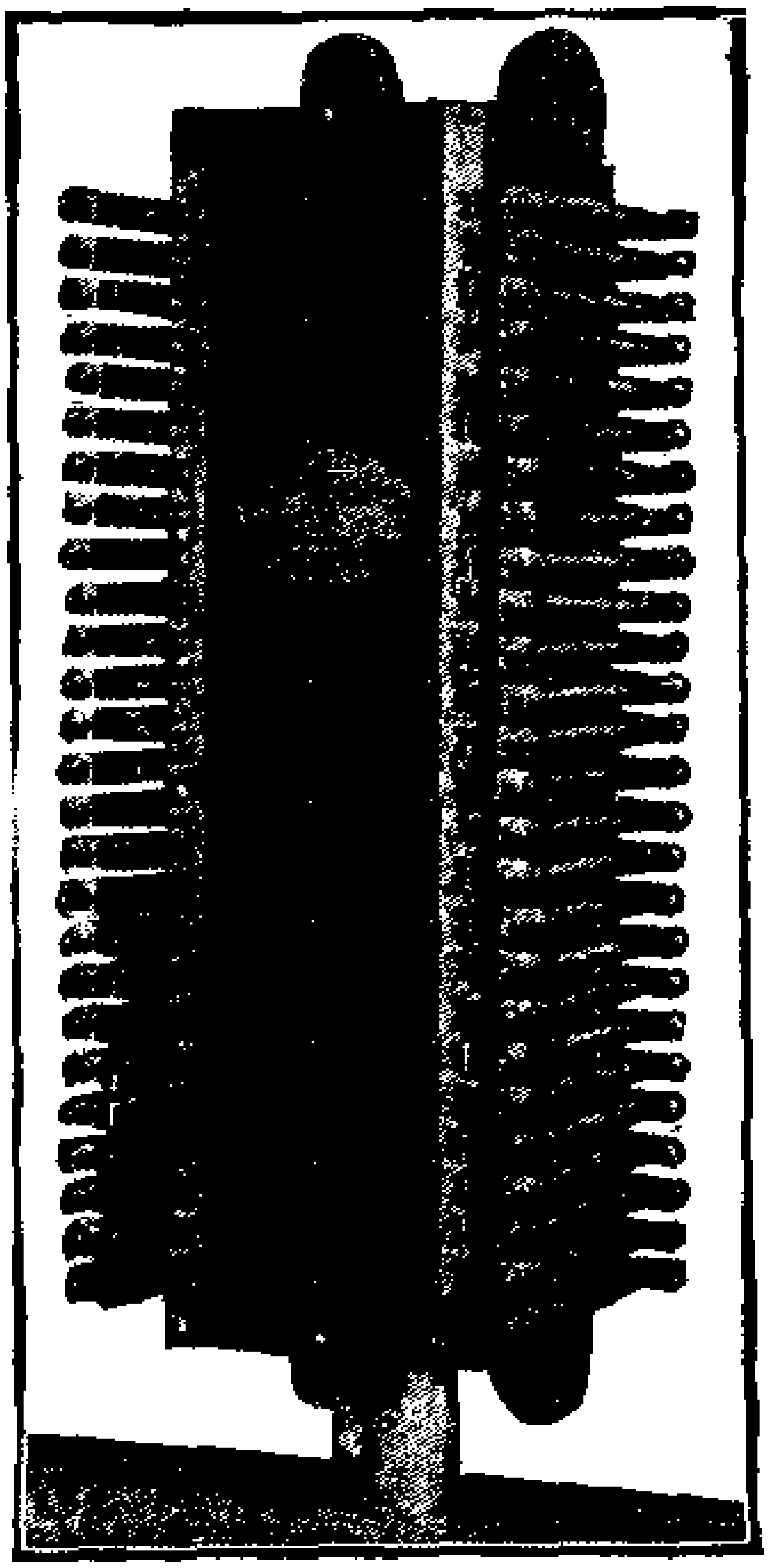


Fig. 9. — Cable Head with Protectors.

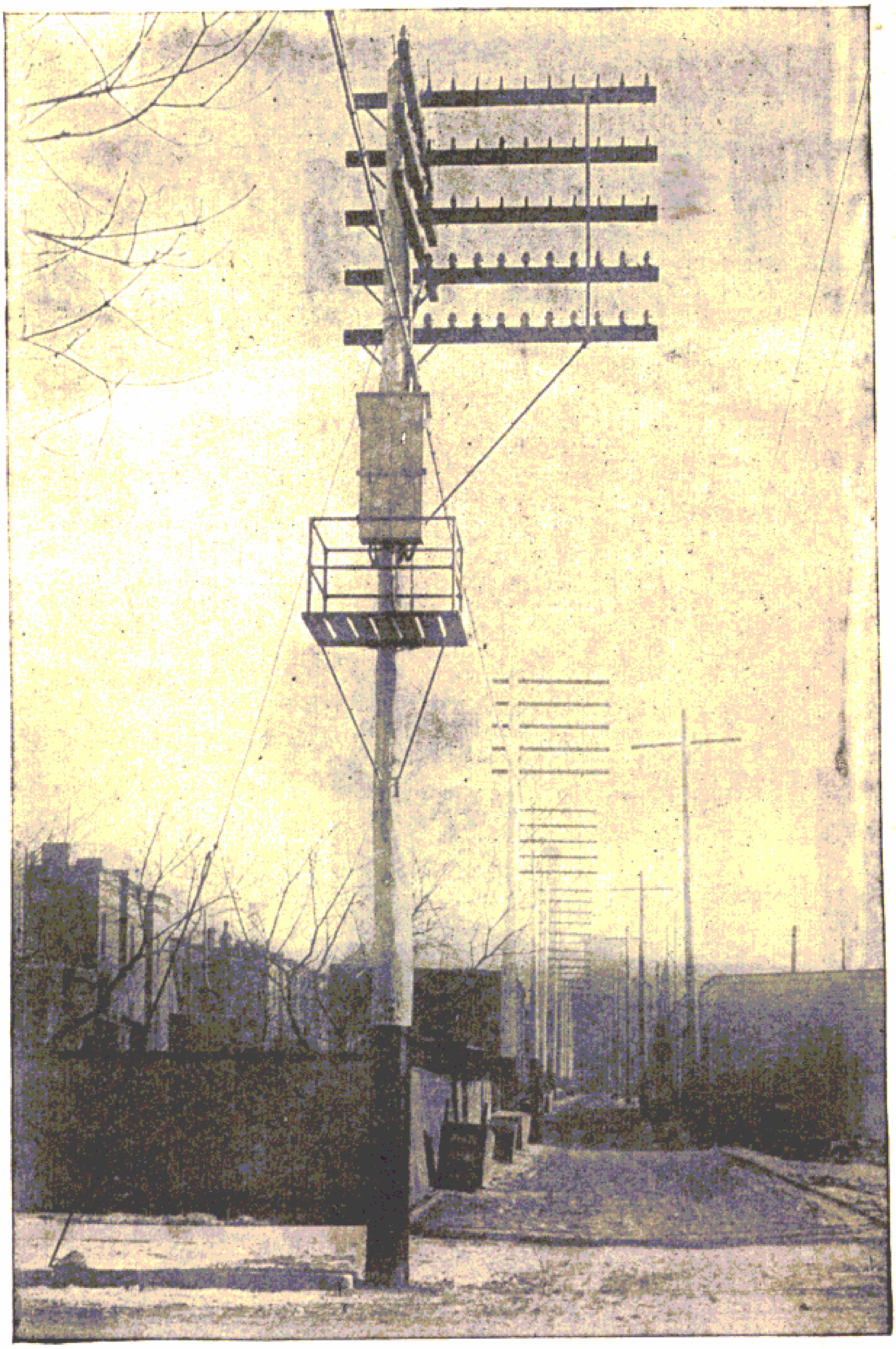


Fig. 10.—Connecting Cables and Open-Wire Lines.

cellent example of "what not to do." No design is displayed in the wiring; on the contrary, everything is at "loose ends." The cable hangs in a sharp bend; and in

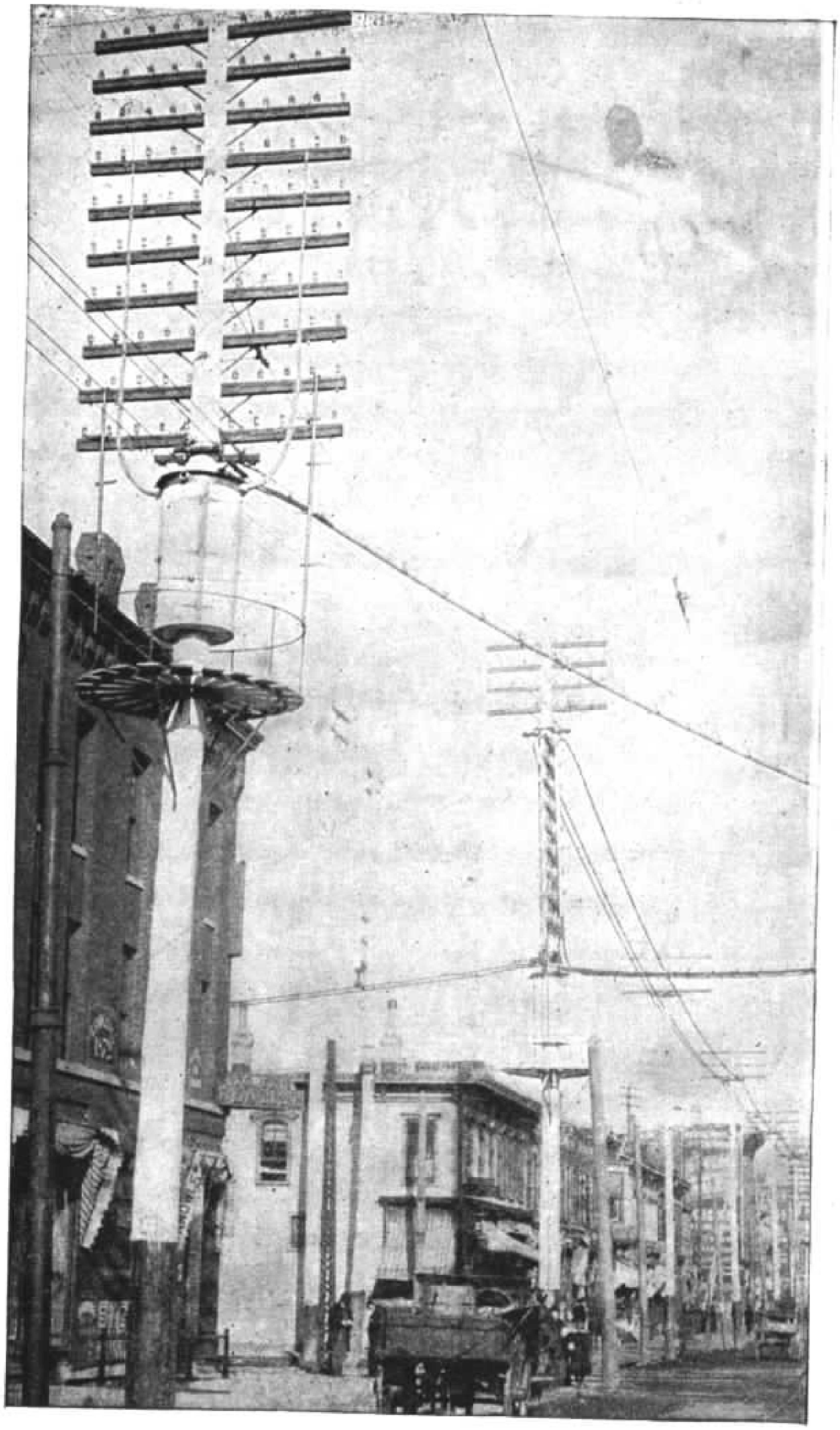


Fig. 11.—Connecting Cable and Open-Wire Lines.

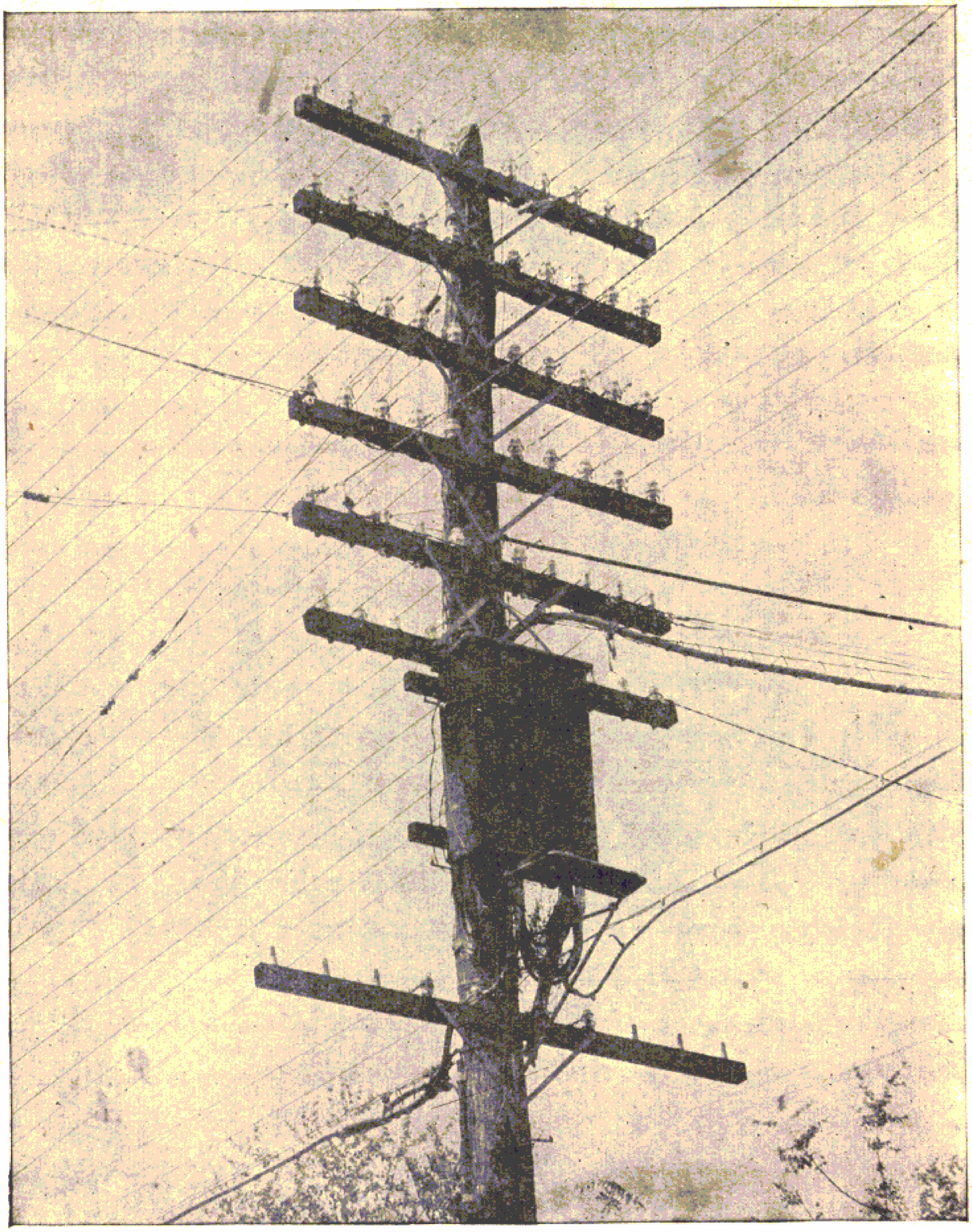


Fig. 12.—"Trouble-inviting" Type of Construction.

general the whole presents a *strong* temptation to the "trouble devil." The details of cable pole box construction are shown in Figs. 13 and 14. If the head shown in Fig. 9

be employed, it is simply bolted to the back of the box, and the jumper forms attached to the ends of the fuses and run down through holes in the bottom of the box (to

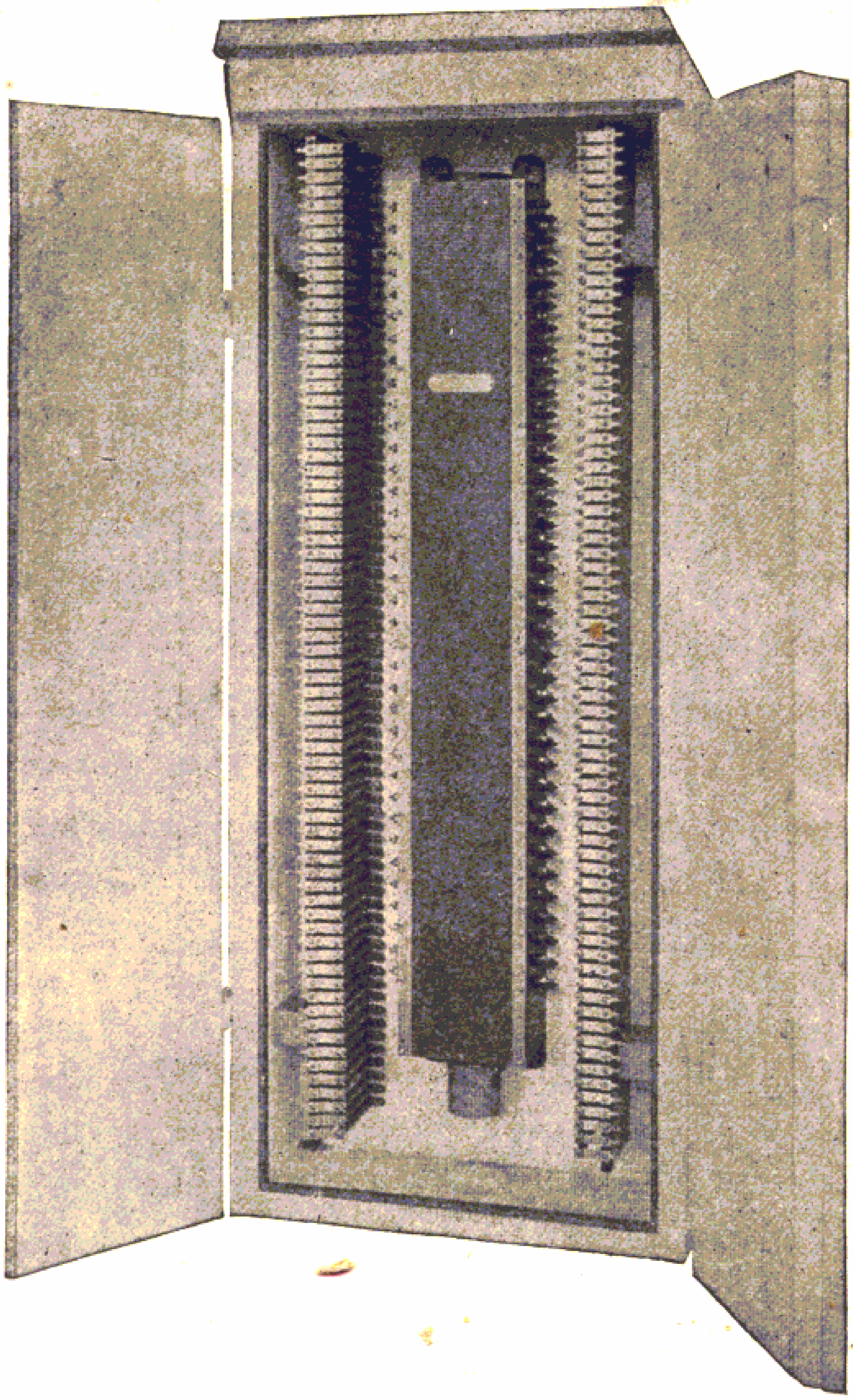


Fig. 13.—Interior View of Cable Pole Box.

prevent the entrance of water), and up to the cross-arms. If plain cable heads are used (Fig. 7 or 8) the box must

be made larger and the protectors placed on strips attached to the back of the box, as shown in Figs. 13 and 14.

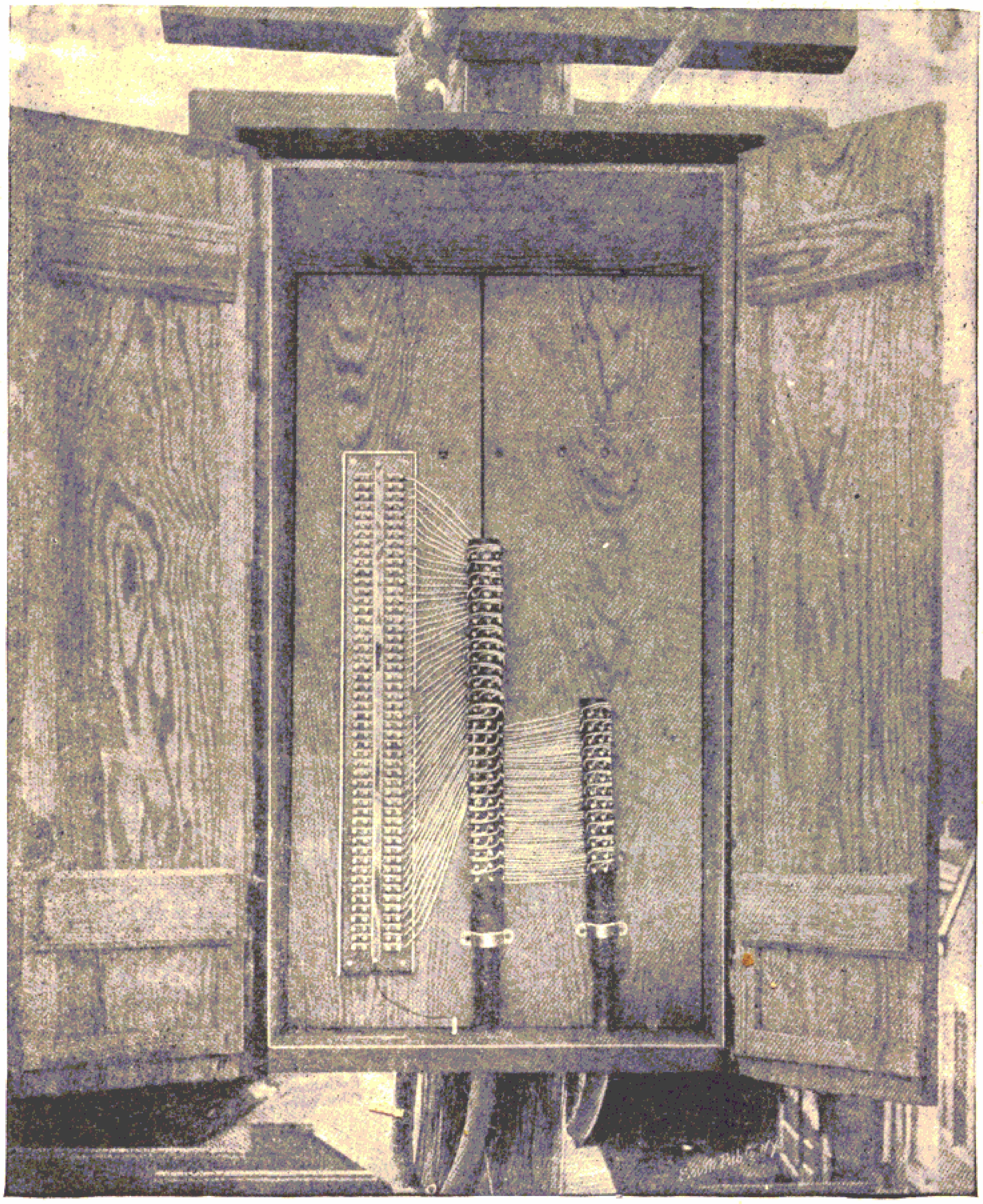


Fig. 14.—Pole Box with Terminal Heads and Lightning Arresters.

A very ingenious pole terminal is shown in Fig. 15, designed to be placed as a cap on the top of the pole.

Fig. 15. — Pole-Top Terminal.

From Fig. 15 it is seen to consist of a heavy iron pan provided with a water-tight cover. The cable enters through a hole in the bottom, to which the sheath is soldered, while the terminal pins project through the circumference of the pan. After being secured in the place on the top of the pole, a copper cover is dropped over the entire terminal, thus effectually shielding it from the weather.

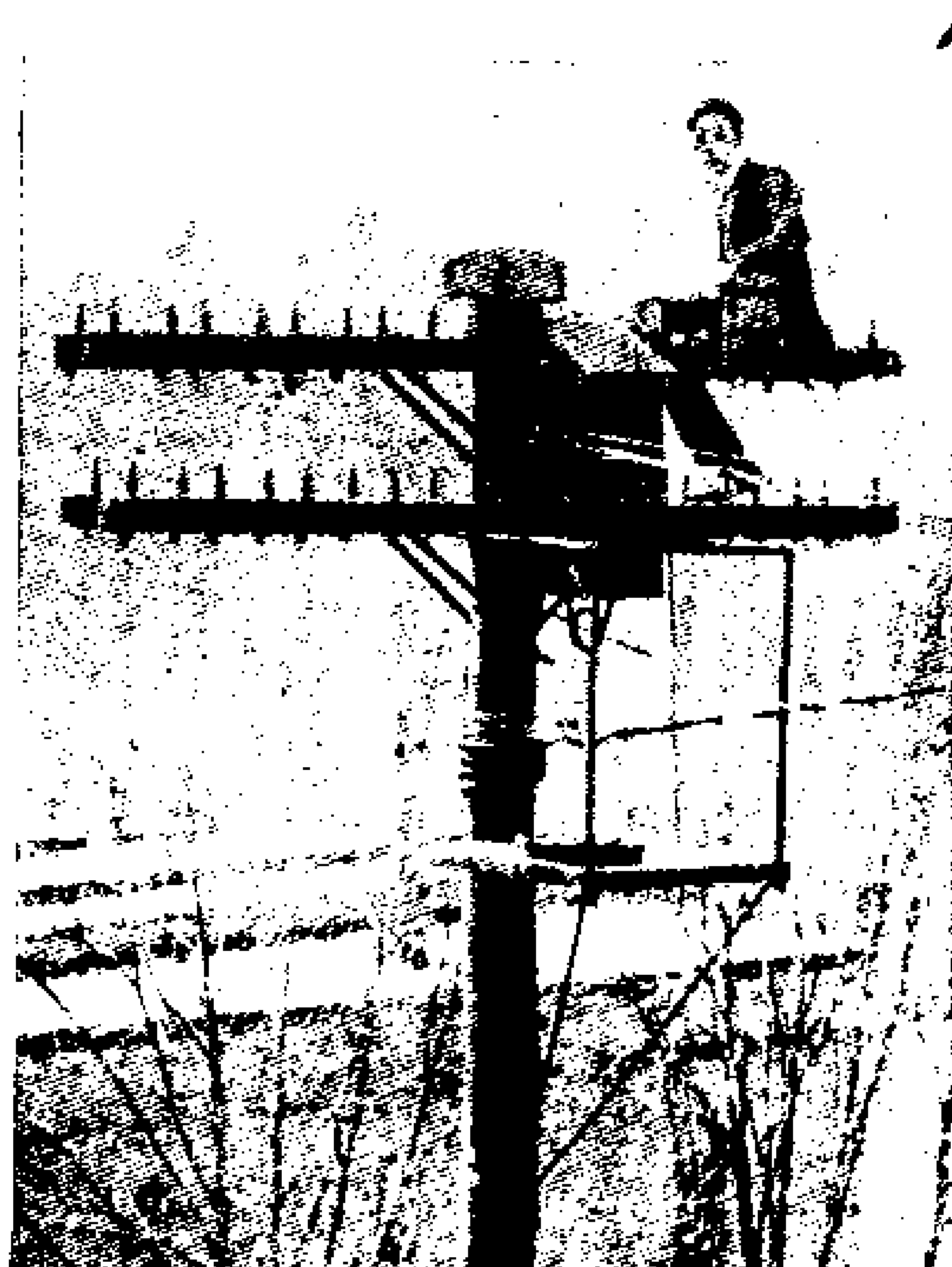


Fig. 16. — Pole Top in Position.

The head is secured to the pole by cutting off the top square and bolting thereon the spider shown at the right hand of Fig. 15. On this the head is attached, the spider also serving to hold subscribers' lines when house distribu-

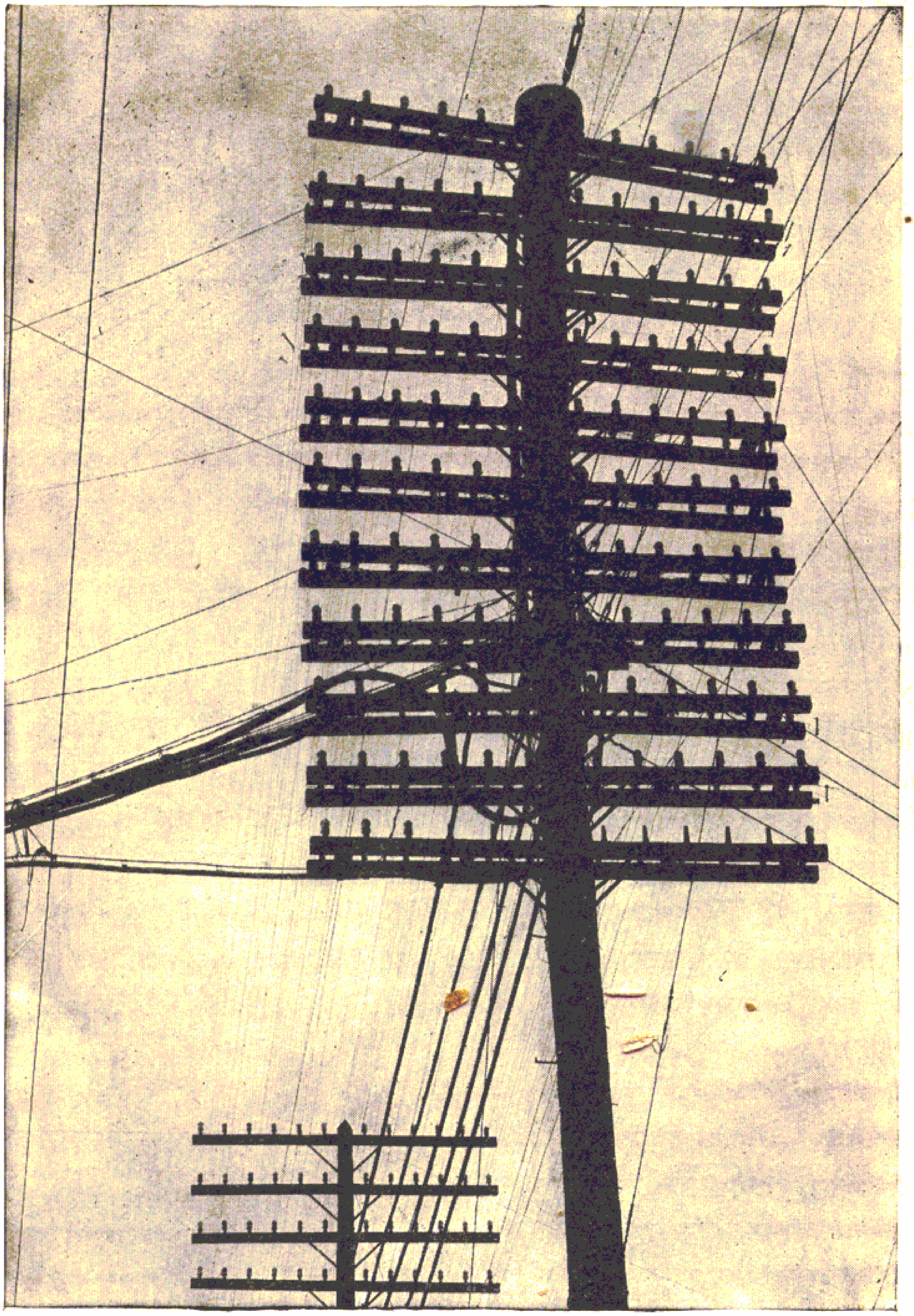


Fig. 17.—Pole Top in Position.

tion is made directly from the cable head. Figs. 16 and 17 show this head as it appears in practice.

Present practice is tending strongly toward the wider employment of cable in all cases, and it is now common to extend aerial cable from block to block, placing a distributing pole in each one, having a cable head into which sufficient pairs are taken by a Y splice to serve the block, and from which the subscribers' drop wire hang in single spans to each house. By this means, rights of way questions are entirely avoided, and a method of distribution at once cheap to install and easy to maintain secured. Fig. 18 is a good example of the general features of this practice, while Fig. 19 shows the detail of distribution.

The pot-head method is so simple as to require little mention beyond the instructions to be found in the "*Cable Specifications*," except to emphasize the absolute necessity of employing as insulating material on the terminal wires some non-fibrous material. Examined under the microscope all silk, cotton or other similar material is found to consist of an agglomeration of fibers, each of which is a little tube. No matter with what apparent care wires covered with such material be boiled in, or saturated with, insulating compound, it is found practically impossible to seal *all* of the multitude of little tubes that can serve to conduct moisture to the paper of the cable. For the pot-head terminal wires there is nothing better than okonite, though this is expensive and inflammable.

Formerly the only method of splicing or pot-heading cable has been to make a "wiped" joint. If this operation is *well done* it is perfectly satisfactory, for thoroughly soldered surfaces are absolutely moisture proof; but wiped

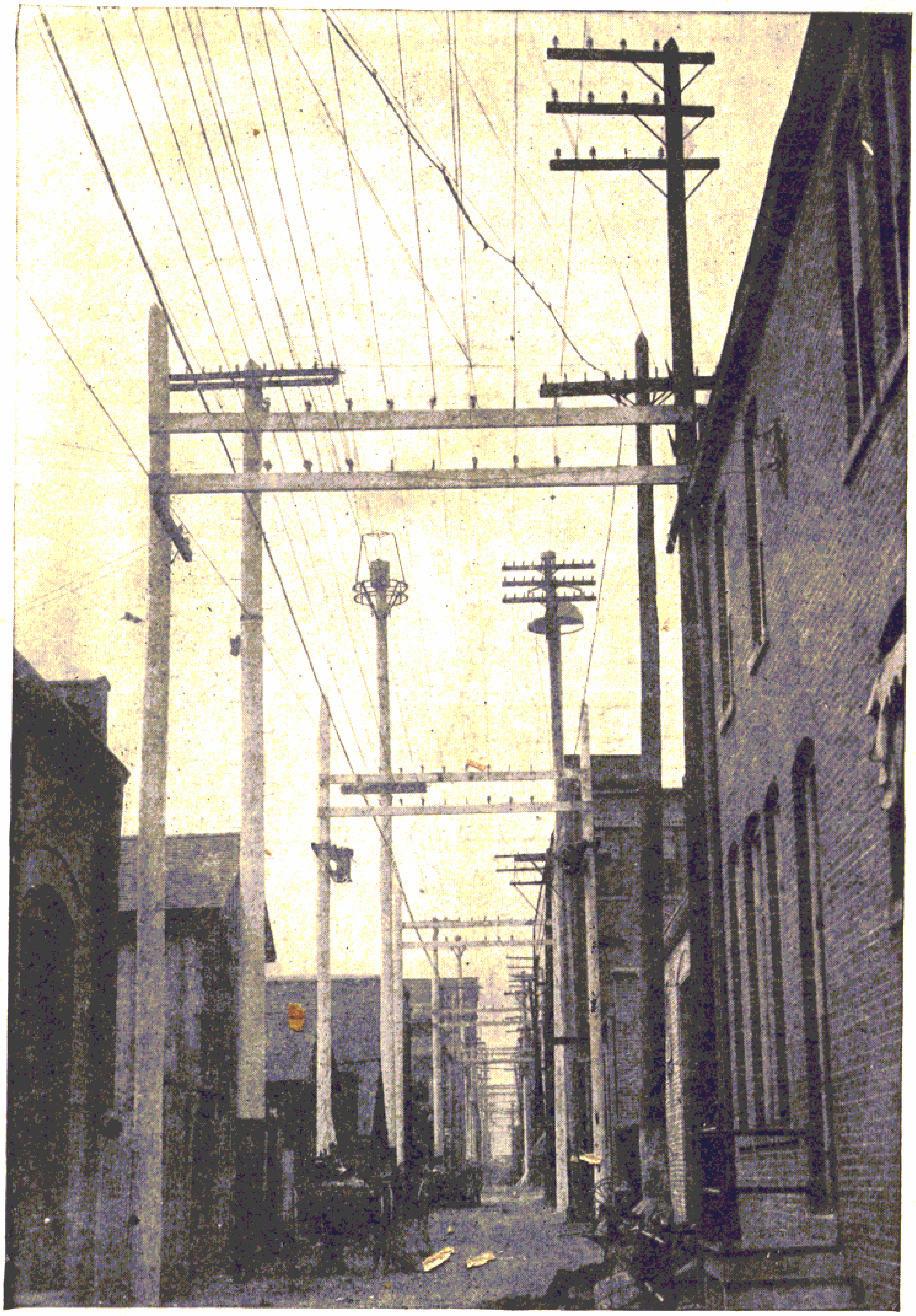


Fig. 18.—Example of Distribution in a Block.

joints are difficult to make under the most favorable circumstances, while on the top of a 60-foot pole, with a kettle of melted lead for a companion, or on the swaying platform of a boatswain's chair, the probabilities of poor

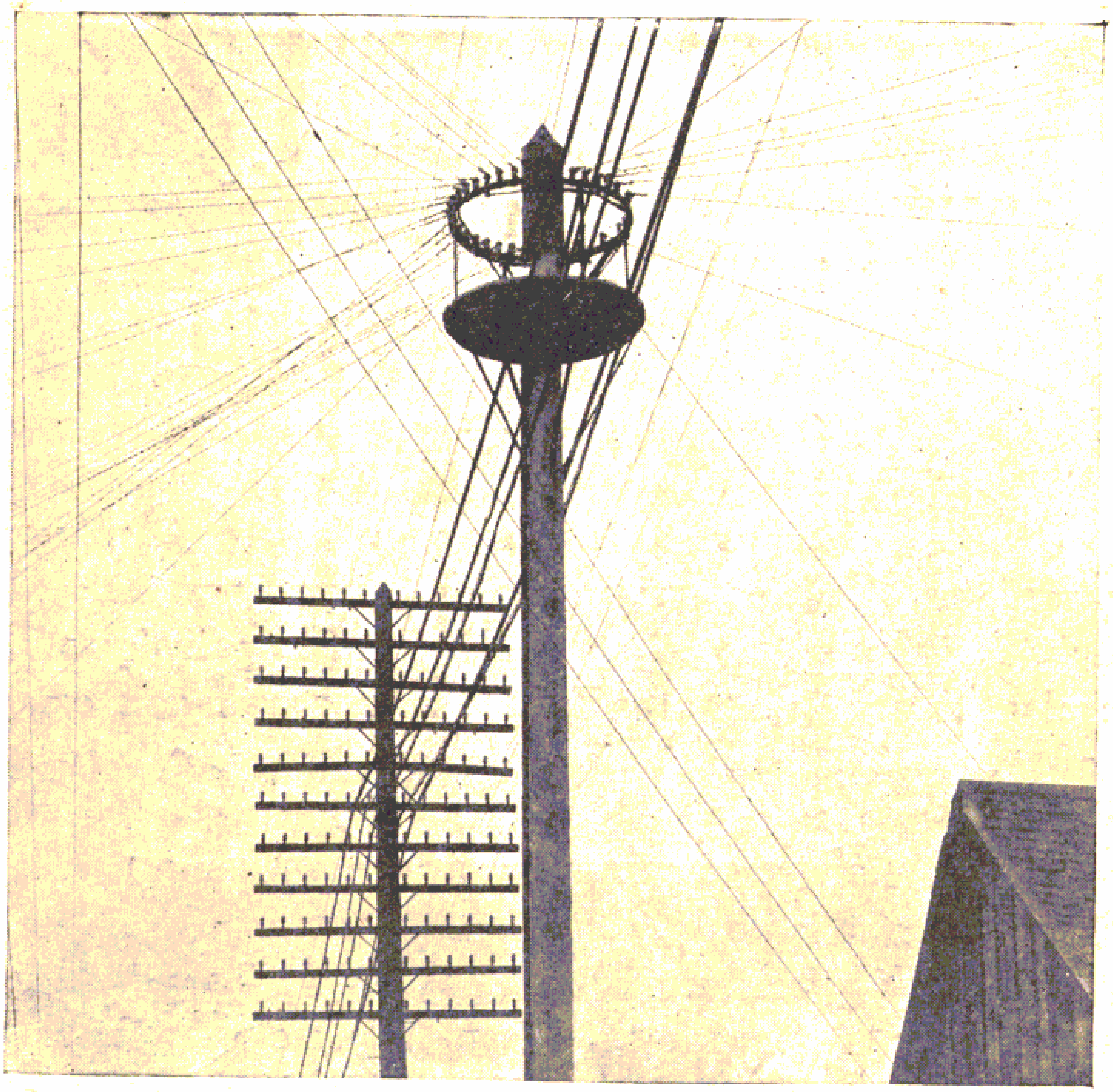
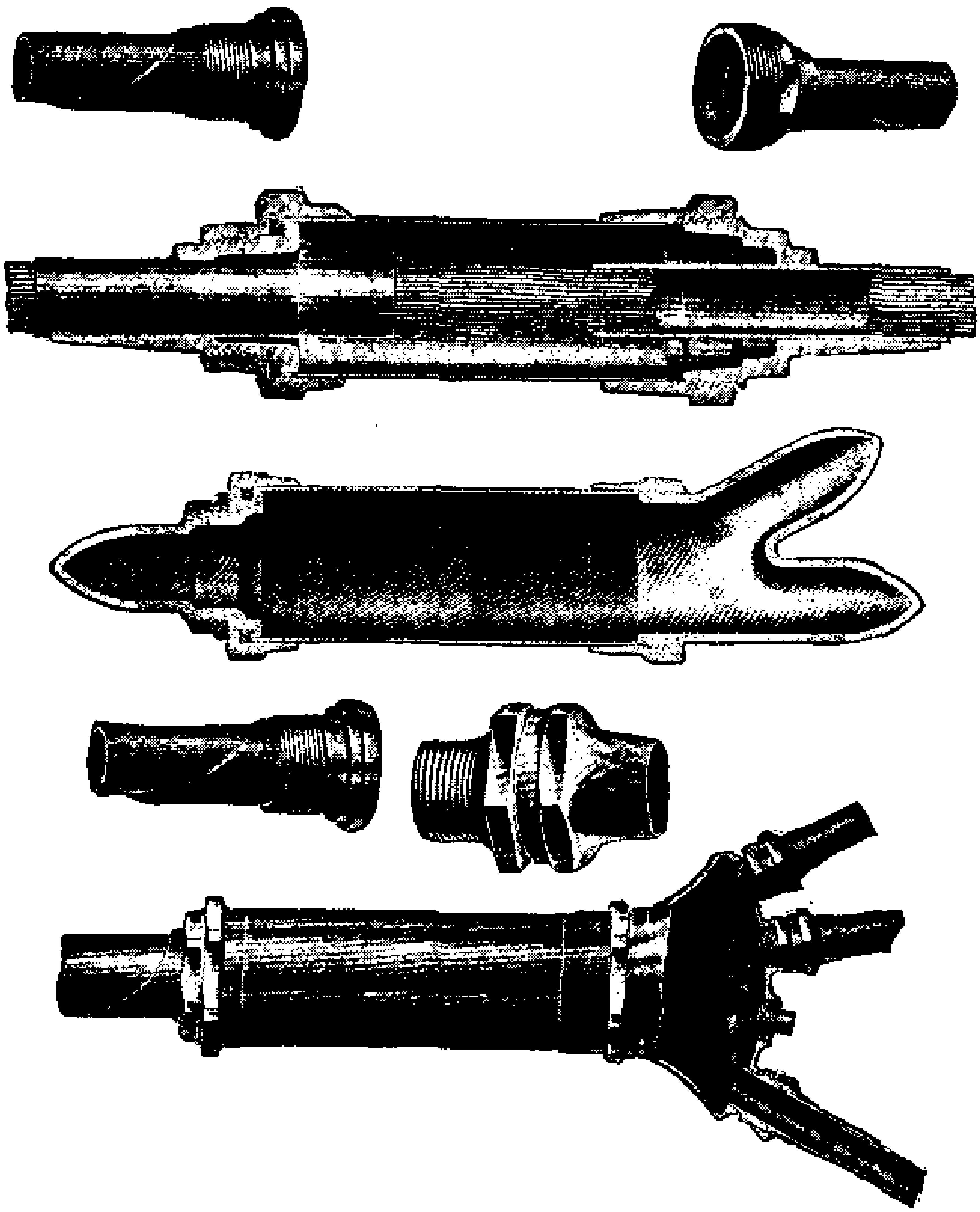


Fig. 19.—Detail of Distribution.

work are much increased. Further, a wiped joint requires skilled labor in the shape of a *plumber* with all the objectionable concomitants of that somewhat unsavory trade.

A method of making joints, splices and terminals has

recently been brought to notice, designed to avoid these difficulties, and further furnishes a method of making connections that possess the incalculable advantage of



Figs. 20, 21 and 22.—Terminals and Methods of Making Joint Splices.

always being accessible to inspection. Figs. 20, 21 and 22 show the plan adopted, and are self-explanatory. The illustrations exhibiting this method as applied to a straight

splice in Fig. 20, a Y splice in Fig. 21, and a pot-head in Fig. 22. In general this device employs a sleeve supplied with special threaded ends, designed to supply a moisture-proof joint. To the sheath of each cable a similarly threaded piece of brass tube is soldered, and the splice or pot-head completed by connecting the tubes with the sleeve by the screw joints. As all parts are interchangeable all soldering may be done on the ground and the ends boiled out, leaving merely the screwing up of the nuts to be performed aloft. This plan is certainly sufficiently promising to be worthy a careful experience test to demonstrate its ability to cope with practical conditions. Unfortunately the expense of the joint (about 50 per cent more than the wiped joint) is likely to be a serious handicap.

CHAPTER III.

INSTALLATION.

To install underground cable would seem a very simple process — simply pull each piece into its duct; but experience has indicated some desirable precautions. By means of the fish wire placed in the duct, as described under "Conduits," a strong yet soft and flexible manilla rope is hauled through the duct, and by its aid a brush and scraper is pulled through two or three times to clear away all accumulated débris. The plan of greasing the cable has been often tried, but with poor success, for while a lubricant may aid in drawing *in* the cable, its presence causes subsequent dust and dirt to so impact the cable that drawing *out* is difficult or impossible. The cable reel is placed adjacent to one manhole, and the pulling appliance at the next one. This may consist simply of an old-fashioned winch, worked by man- or horse-power, but a far preferable, better and more economical device is a steam or gasoline motor geared to a small hoisting engine. The rope from the pulling machine, whatever it may be, is now attached to the cable, and here particular care is necessary, as the pull must be carefully distributed to the sheath. The best plan is to use a brass tube, a foot or more long, but slightly larger than the sheath to which it

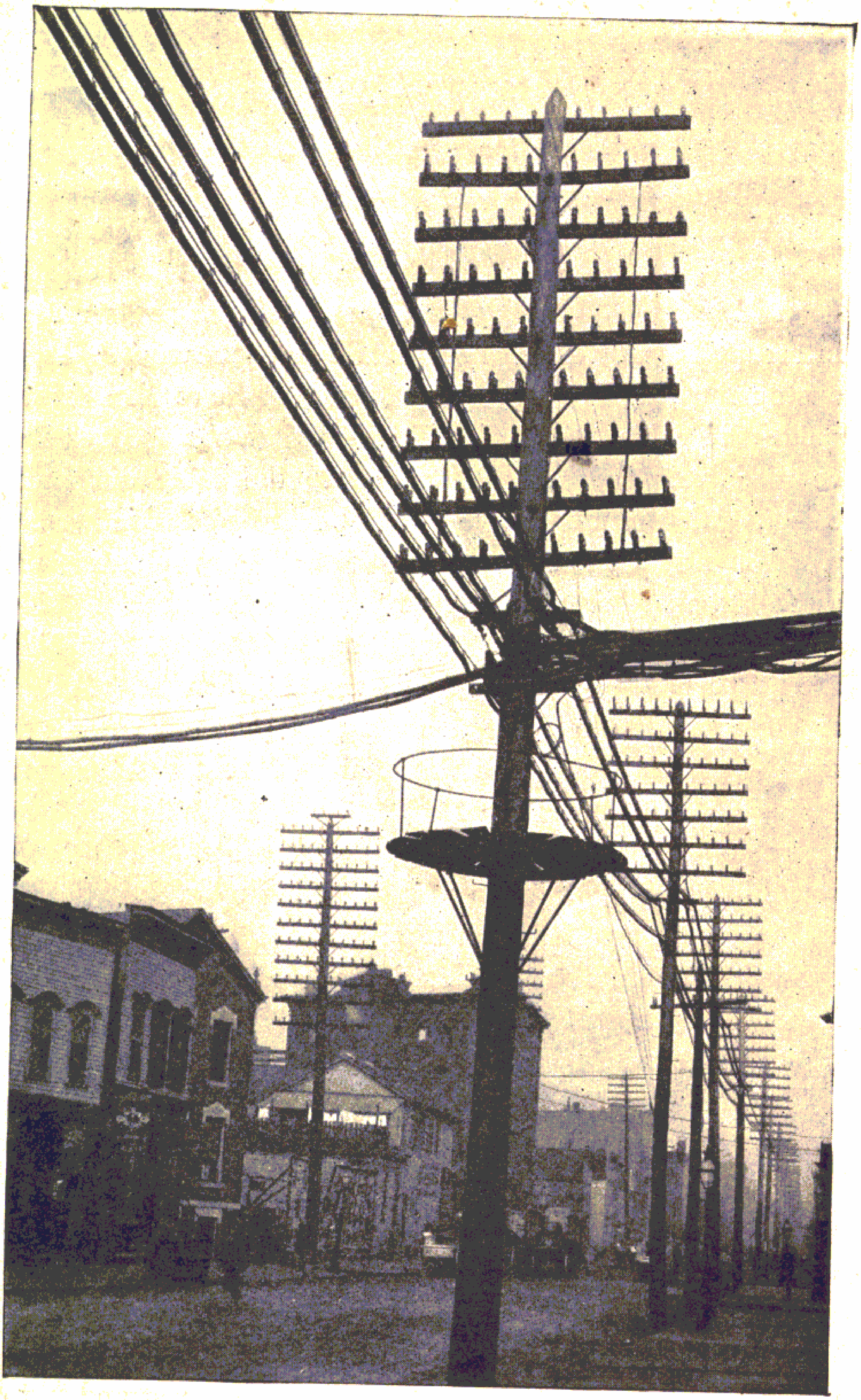


Fig. 23.—Aerial Cables.

may be soldered. The end of the brass tube is supplied with an eye to which the rope is attached, and thus the pull distributed evenly to the entire lead. When all preparations are complete the drawing is started and should proceed slowly, steadily and uniformly, without interruption, till the desired manhole is reached. It is customary to place at the reel one or more sheaves to guide the cable. With small sizes, when the sheaves can be made very large in proportion to the cable diameter, this is good practice; but with 2-inch or $2\frac{1}{2}$-inch cable there is rarely enough room to work rollers of sufficient diameter, and it is preferable to have a gang of men guide and feed the cable into the duct, the mouth of which should be protected by a conical shield of leather. As far as possible it is desirable to order cable of such lengths as can be drawn from point to point in the underground system. The various pieces are then supplied by the manufacturers with sealed ends, and there is little or no waste in cutting. Splicing follows next upon drawing in, and in case a length is cut from a reel, it should be either spliced, or the cut end sealed immediately, for even a few hours' exposure of an open end to the damp atmosphere of conduit vaults will injure cable insulation.

The installation of underground cable is limited to drawing the cable into its duct. Aerial cable is suspended from pole lines; is necessarily placed in very diverse locations, and in far more exposed situations, hence the opportunity for "engineering" is much wider. Cable is far too frail to hang unsupported from pole to pole. It is customary therefore to run a wire rope $\frac{3}{8}$ inch to $\frac{5}{8}$ inch in diameter, called a "messenger wire," or "strand," to

which the cable is at frequent intervals, as often as 18 inches to 2 feet, attached.

The strand is attached to the poles in case of an ordinary open-wire line, as is indicated in Fig. 23, or to the rack of a house-top fixture, as in Fig. 24. By this method circuits may be carried over very long spans many

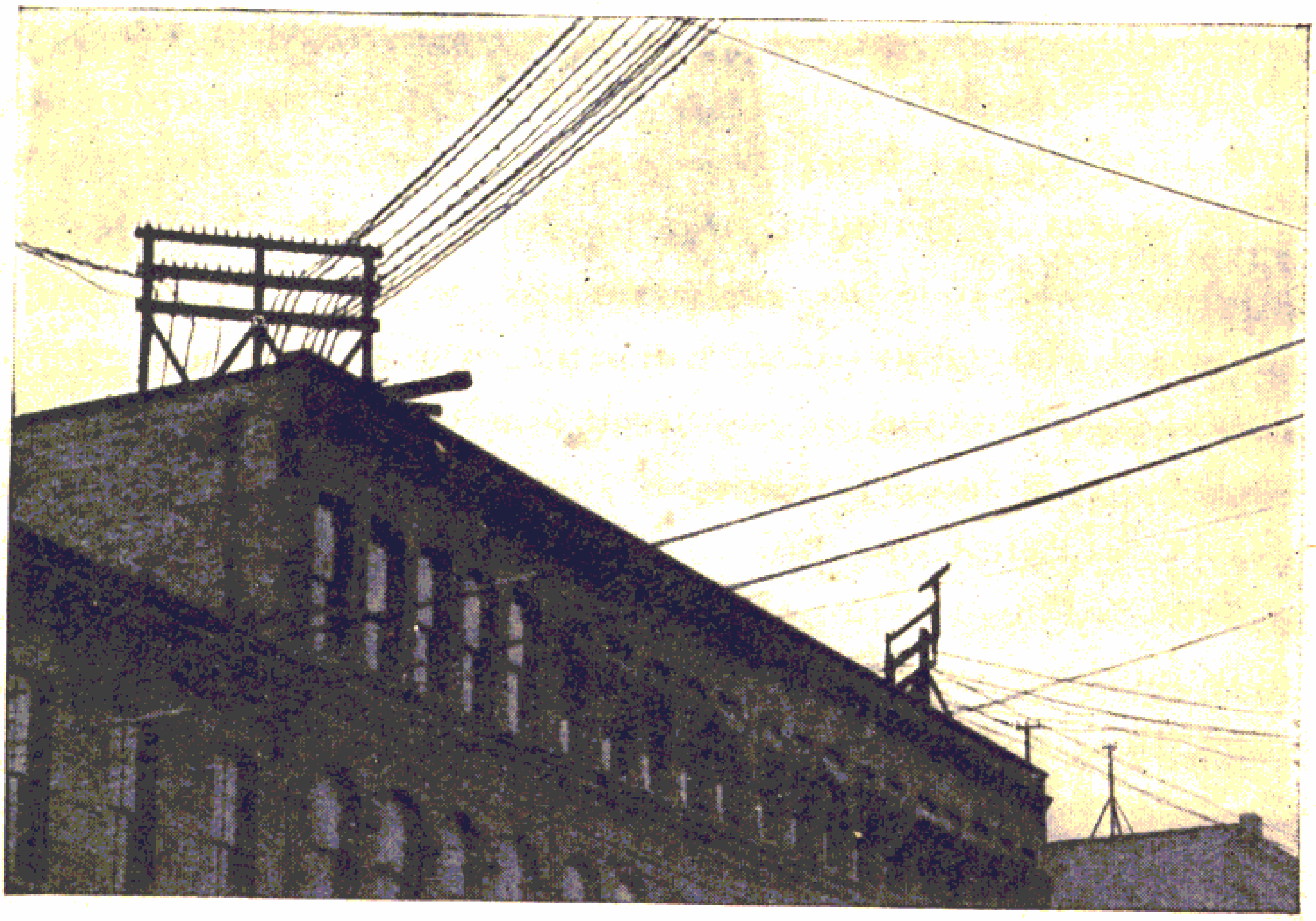


Fig. 24.—House-Top Fixture.

hundreds of feet, as illustrated in Fig. 25, more cheaply and safely than by any other device.

When there are not more than two cables the strand is most conveniently supported by the method of Fig. 26, but if there are a greater number, an angle iron cross-arm, bolted to the pole, is by far the best method, as is illustrated in Fig. 23. Hundreds of devices have been ad-

vanced for attaching cable to the messenger, a few of the more successful of which are shown in Fig. 27. The

Fig. 25.—Long Span of Aerial Cables.

chief requisites are ease and cheapness of application; permanence, i.e., freedom from slipping or unhooking, and no injurious action to the lead of the cable.

Few of the modern cable hangers meet these characteristics better than the old-fashioned marlin loop, shown at A, Fig. 27. Well tarred marlin will last nearly as long as the cable. If the hook be closed there is little tendency for the cable to leave the strand; with each sway of the wind the slip nose hugs more tightly and rarely slips; and lastly, this is one of the quickest and cheapest methods of application. Another plan of support is that of the "Spinning Jenny," as exhibited in Fig. 28. A split spool is clasped about both cable and strand, and then filled with marlin. When spool is hauled along, it lifts the cable close to the strand and lashes it in place. Unfortunately, this plan is open to the objection that if the marlin gives way at any point, the entire span is lost and the cable precipitated into the street.

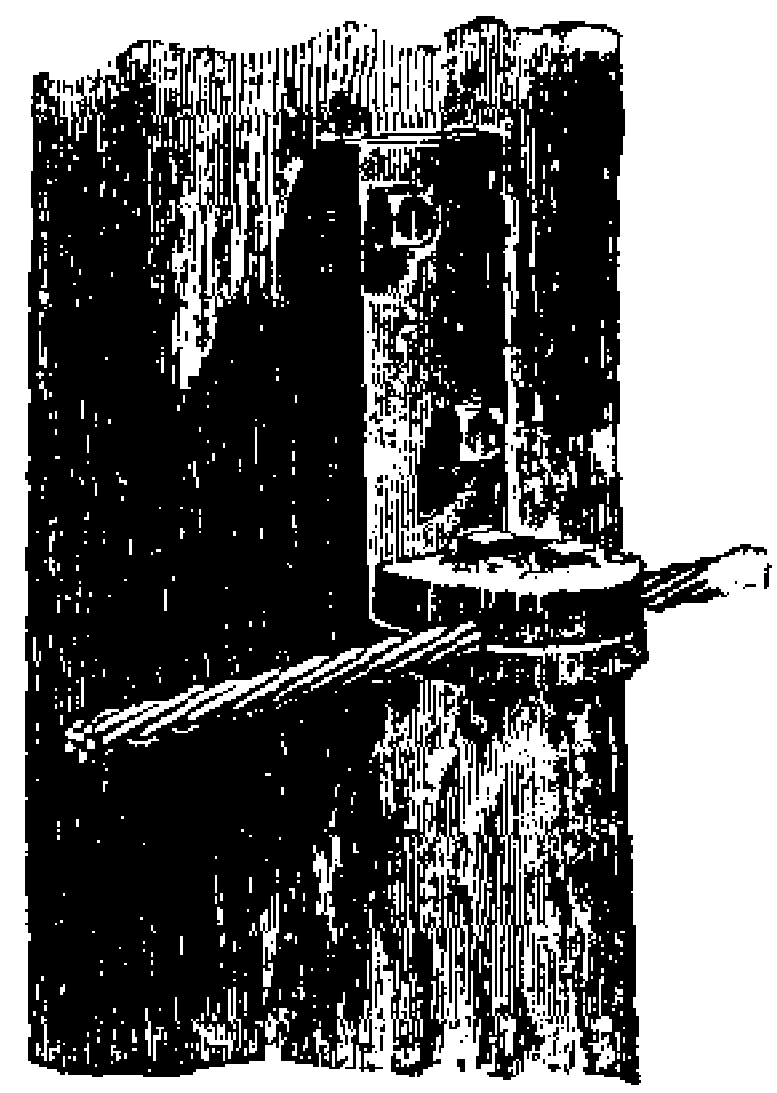
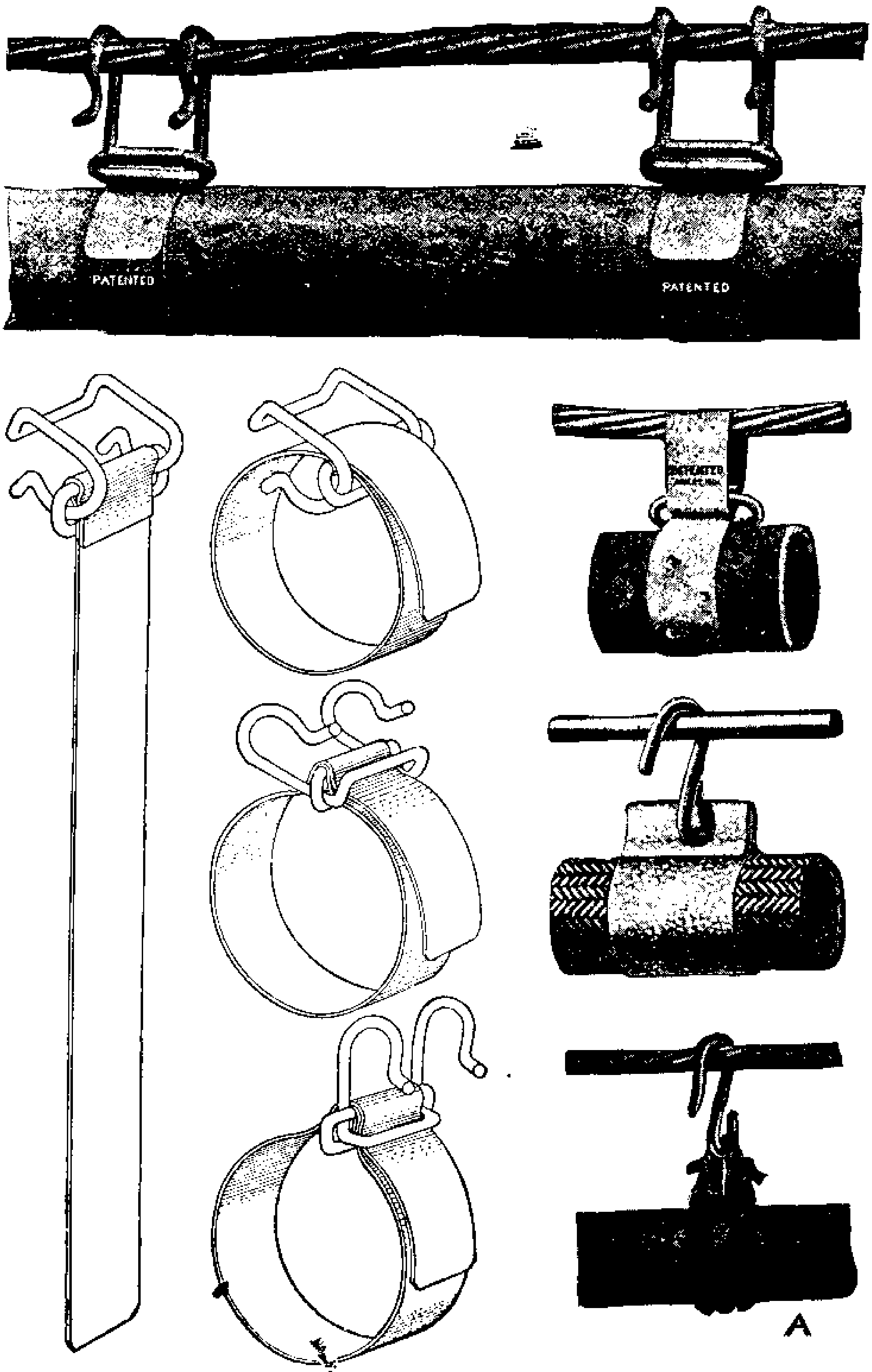


Fig. 26.—Messenger Pole Supports.

The weight of aerial cable is a very great addition to even the strongest pole line, and this form of wire plant should never be attempted unless the pole line be specially designed for the purpose. All corners and anchorages must receive special attention also, and be designed to bear the extra stress inflected on them. For further details relating to cable construction, the reader is referred to the *Cable Specifications*.

To carry the underground wire plant into the central office it was customary to tunnel under the street, from the end of which the various ducts diverged. The sides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and roof of the tunnel were provided with racks set about three feet center, on which the cables were supported. Such a method is shown in Fig. 29. Modern practice cheapens construction by omitting the tunnel, and con-

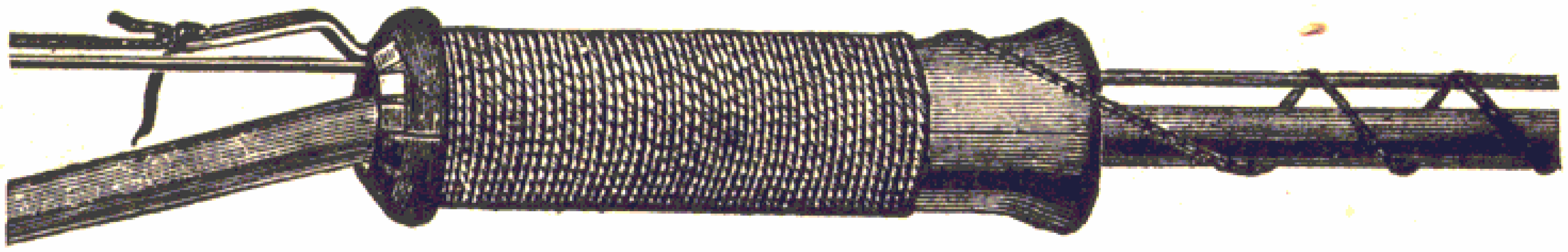


Fig. 28.—Cable-Spinning Jenny.

Fig. 29.—Cable-Supporting Racks.

tinues the underground conduits into the basement of the office building; or even in cases where the distributing board is placed on an upper floor the walls of the building are formed of hollow brick, and the underground cable

Fig. 30. — One Method of Leading Cables into Office.

continues uninterruptedly to the wire-chief's room. Whenever there are corners to turn either a manhole for the purpose must be built to give access to all cables, or else iron-pipe bends, of about five feet radius, must be introduced into each duct through which the cable can usually be drawn.

Fig. 31.—Another Method of Leading Cables into Office.

Office entrances for aerial cable are as varied and numerous as there are exchanges. The most common method is to plant a distributing pole in front of the building to which all lines, both open wire and cable, converge. Cable heads are placed here, and all lines cabled and run through a hole in the building-wall. A good example of this type

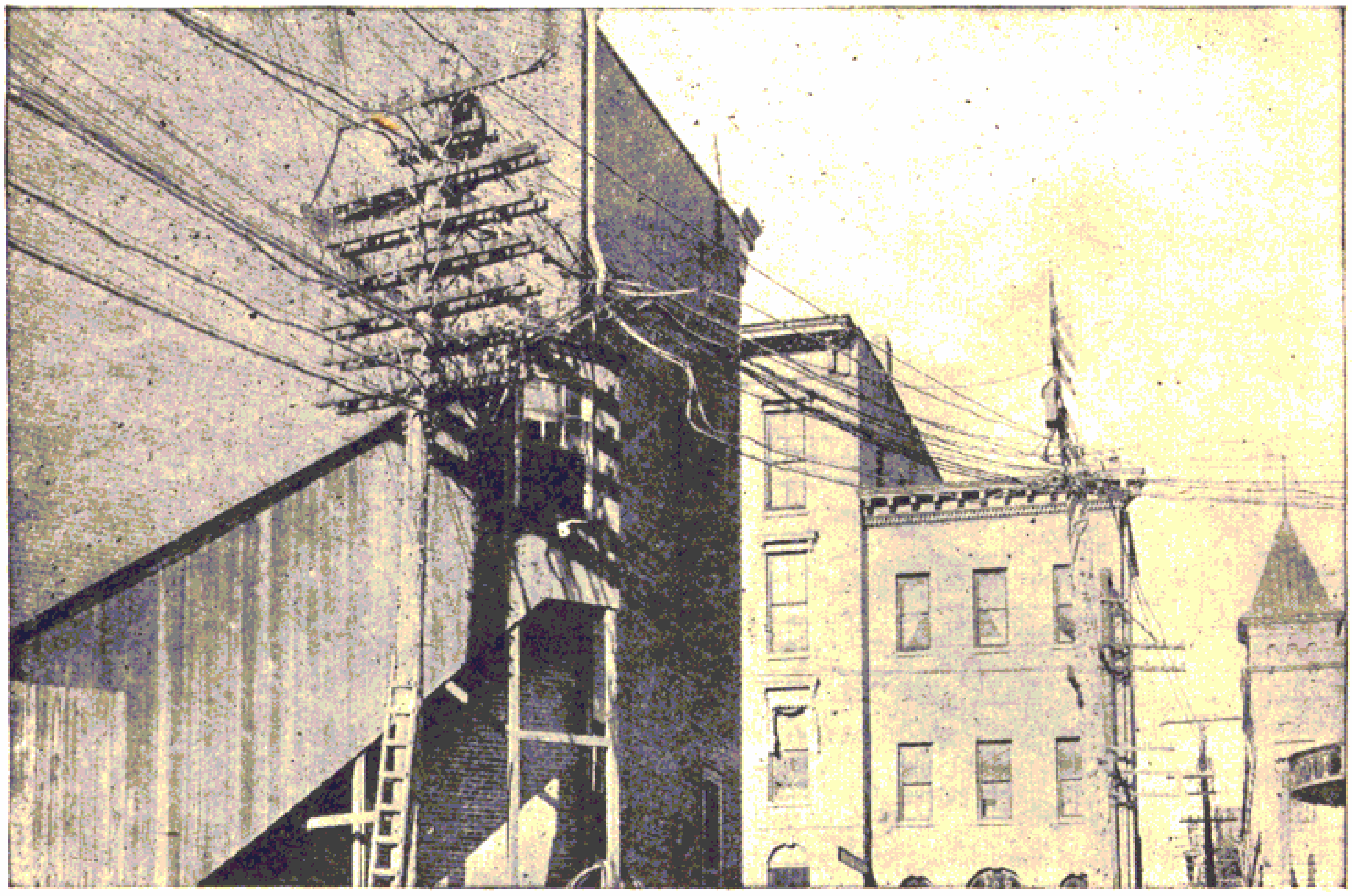


Fig. 32.—Where "Bugs" Breed.

of construction is shown in Fig. 30. A still more modern method, when the plant is entirely composed of aerial cable, appears in Fig. 31. In Fig. 32 an unfortunately far too common example is found. Up against the office-wall any old pole is erected. To this all the circuits, cable, strands, and open wire run as best they may. The wire chief punches out a few bricks from the office-wall, and drags through the crevice a handful of okonite to

serve as office cable. Result, endless complaints. Yet this is a photograph from recent work of one of the Western Independent Companies that six months ago, in convention, voted that "*the maintenance of a telephone plant should not exceed five per cent per annum!*"

CHAPTER IV.

THE QUESTION OF ELECTROLYSIS.

PRIOR to electric railway days, telephones were universally provided with grounded circuits, but the return currents of trolley roads caused such lines to become unbearably noisy; and a long and bitter warfare was waged between the telephone interests and the street railways, with a view of forcing the latter to abandon the rail return. In this contest the telephone companies were universally defeated, for it was impossible for a single industry to advance any just claim to demand the exclusive use of the earth as a return circuit.

Shortly after the victories of the street railways a number of cases of corrosion of water pipes, gas pipes, and the lead sheaths of telephone cables, made their appearance, that on investigation were conclusively found attributable *to the electrolytic action of railway currents.* Armed with this discovery, the telephone companies returned to the fray, and became almost hysteric in their assertions of the immediate and inevitable destruction that menaced all metallic underground structures. It was confidently asserted that every gas and water system in the country, together with the elevated railway structures and metallic foundations of modern buildings, was not only in danger

of destruction, but that already incalculable injury had actually been inflicted. So plausible were these specious assertions, and so skillfully advanced, backed with scientific authority of weight, as to create at least a newspaper panic against the single-trolley system. Continued investigation and wider experience proved that the alarmists had, to say the very least, grossly exaggerated the probable danger. The actual facts as they stand to-day may be summarized as follows:—

First, when an electric current passes *from* the earth to a metallic body imbedded therein, there is *no* injurious action.

Second, so long as the current traverses the metallic body, no injurious effect is produced.

Fig. 33.—Corrosion of Lead Cable-Sheathings by Electrolysis.

Third, when the current leaves the metallic conductor, and re-enters the earth, injury may, but does not necessarily, take place.

Fourth, when injurious action does take place, it manifests itself as a corrosive pitting of the surface and substance of the metal as exemplified in Figs. 33 and 34. Fig. 33 being a piece of lead service water pipe, and Fig. 34 a bit of the lead sheath of a telephone cable. This action results in a number of perforations of the metal, and may even spread so far as to cause a wide-spread destruction.

Fifth, a very small difference of potential between the metal and the earth (a hundredth of a volt) may be sufficient to cause an injurious action which will be cumulative, and will in time result in extensive destruction.

Sixth, it is easy to locate danger areas, and to provide protection by leading away the pernicious currents by some conductor that is not injured thereby.

Fig. 34.—Corrosion of Water Pipe by Electrolysis.

Seventh, various metals exhibit very different degrees of sensitiveness to corrosion, lead being the most susceptible, wrought iron much less, while cast iron, particularly the hard white varieties, is frequently if not always immune.

Eighth, though the electric railways have been in widespread operation for more than a decade, the gross injury so far discoverable, is of relatively small amount, and has

been chiefly limited to the corrosion of a number of telephone cables, the perforation of lead service pipes, and small gas and water mains. A few isolated cases of injury to large mains, and the fall of a stand-pipe at Peoria, Illinois, attributed entirely to electrolysis, are the only instances of capital injury on record; but the expert testimony in a suit brought to recover damages from the electric railway company of Peoria, leaves room for reasonable doubt as to whether the railway current was *solely* responsible for the collapse of the pipe, though undoubtedly it played a part therein.

Ninth, usually street railway companies have shown themselves keenly alive to the consequences of electrolysis and anxious to co-operate to any reasonable degree to secure the protection of underground structures.

So long as electric railways employ an uninsulated return, there will always exist the possibility of injurious action to underground metallic structures. As the lead sheath of telephone cables is particularly sensitive, and as even a minute perforation of the lead will destroy an entire section of cable, by the admission of moisture, a frequent and thorough inspection of the underground plant is essential. This examination is usually accomplished by testing each cable in each manhole to see whether it is negative or positive to the surrounding earth; that is to say, whether the current is flowing *from* the earth *into* the cable, or from *the cable* into the *earth*; and the ease, rapidity and cheapness with which this examination can be made, warrants frequent repetition. A single inspector, provided with a helper to lift manhole covers, is all the force needed to examine many miles of cable per day.

The inspector must be provided with a low reading voltmeter, reading in both directions from zero in the center of the scale. An instrument with a scale of about 10 volts on either side of the center, and capable of being read to 1-100 of a volt, is best suited to the purpose. From the positive terminal a flexible conductor made of good rubber-covered lamp cord, is extended to a pair of hand gas tongs, the jaws of which have been filed smooth. From the other terminal a similar flexible cord is carried to a light, sharp-pointed iron rod, three or four feet in length. The sheath of each cable to be tested should be thoroughly cleansed with a few strokes of emery paper, and then grasped with the gas tongs, thus insuring good contact of the positive wire. There is likely to be more difficulty with the negative pole in securing a good ground. If the vault has a sewer connection, the trap will usually be found full of water, and a good earth may be obtained by dropping the iron rod into it. In other cases, it may be necessary to get an earth by driving the rod between the paving stones into the ground, deep enough to reach moisture. It is inexpedient to ground on a neighboring water or gas pipe, as these structures are quite likely to be at a different potential from the earth, and so give readings leading to incorrect conclusions. When a proper earth is obtained, the volt meter is observed a deflection to the right, indicating that the cable is positive to earth, and one to the left that it is negative. Careful notes of the date, time of day, and designation and location of all the cables tested, should be made, as the electrical history acquired from repeated inspections becomes of great value.

Telephone companies have at their disposal, in the wire network ramifying throughout the entire territory served, peculiar facilities for ascertaining the electrical conditions of the earth. If each subscriber's line be grounded at the sub-station, and at the office, it is easy to measure the potential difference. This process is exactly analogous to that of the topographical engineer who, after running a series of levels over a country, can plot a map showing by contour lines the relative hills and valleys of the territotory surveyed. Electrical leveling is even more simple and quickly performed. To continue the analogy, the electrical leveler stations himself in the central office, and is provided with a voltmeter, one terminal of which is connected to a ground wire, while the other is supplied with a single cord and plug, fitting the jacks of the switchboard. The rod-man proceeds to one sub-station after another, and from each calls up the office notifying the leveler to take a reading, at the same time grounding the subscriber's line. The leveler plugs the voltmeter into the subscriber's jack and reads, instantly obtaining the potential difference, or variation in electrial level between the office and the subscriber's station. In such a survey, the time consumed is chiefly that required by the rod-man in going from one sub-station to another, for less than a minute at each is sufficient to call the office and secure a reading, so by having several rod-men hundreds of stations may be tested per day with the utmost facility. As the locations of the sub-stations are known, it is easy to plot on a good map the observed potential differences, and then lines drawn through all those of equal value form equipotential curves or electrical contours. Such an in-

vestigation may be termed an Electrolytic Survey. Fig. 35 shows the results of such an examination made by the writer in the city of Toledo, O. The contour lines are drawn at intervals of one volt, and show in the most salient manner the distribution of earth potential, and the gradual rise that takes place radially away from the power

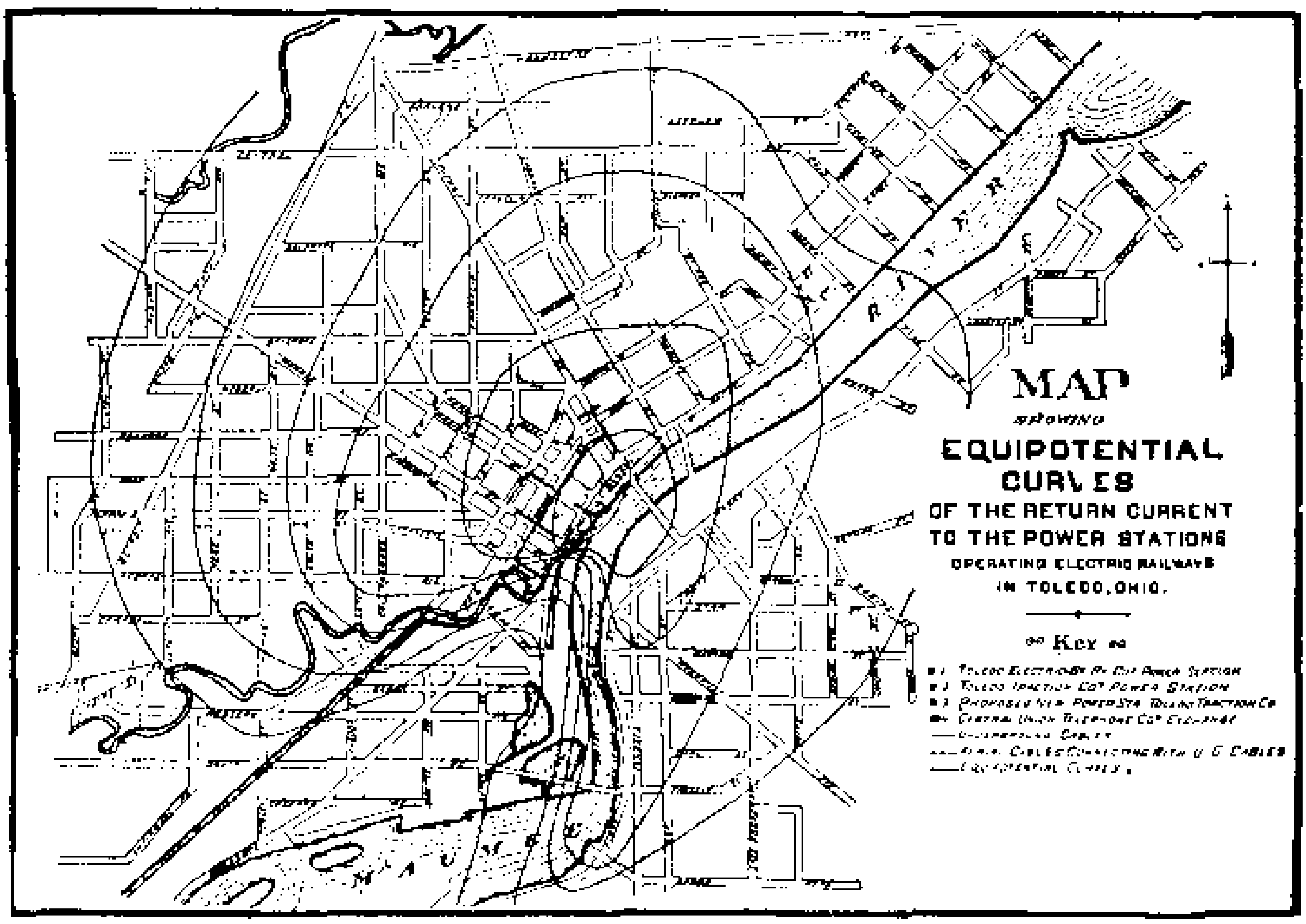
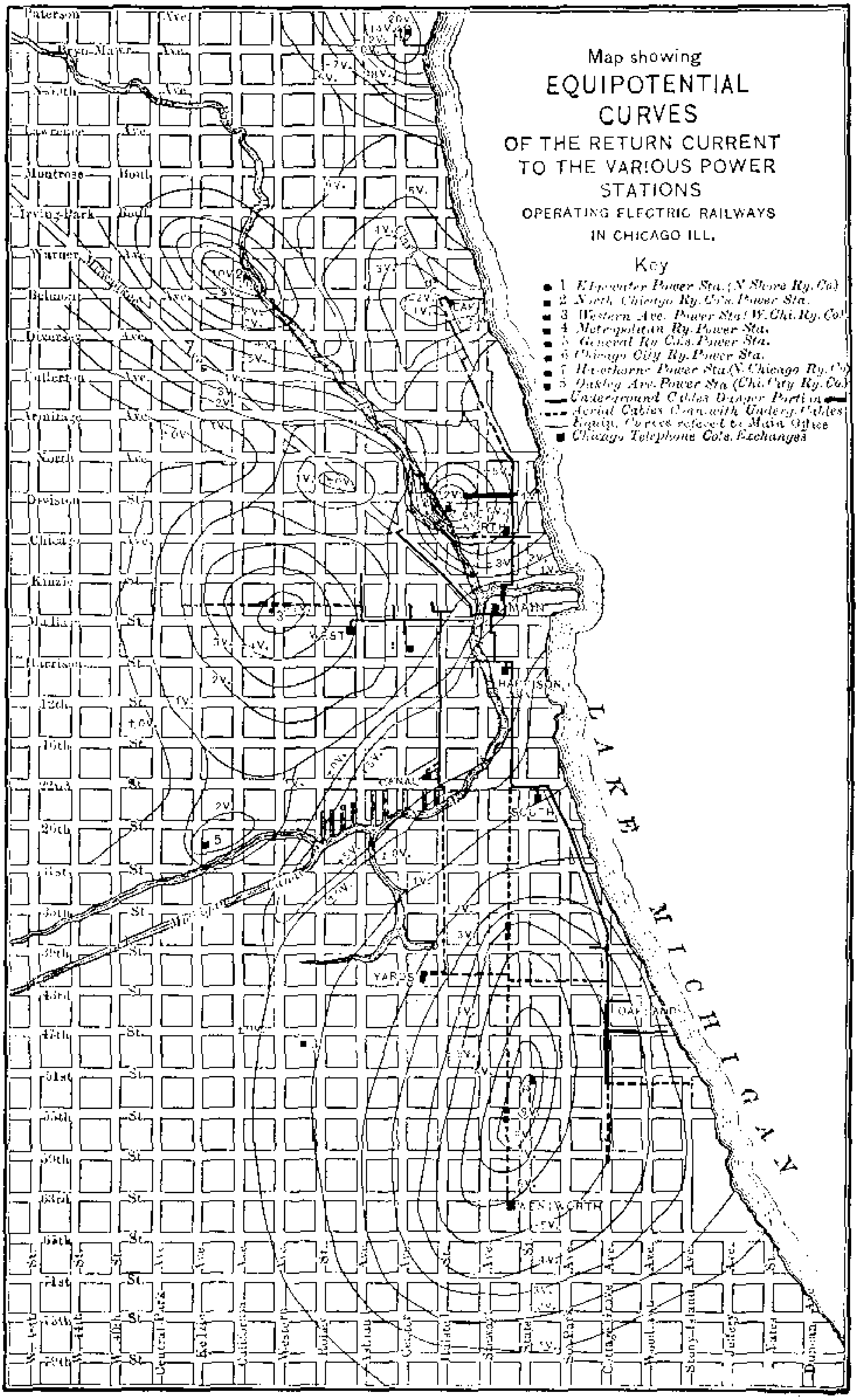


Fig. 35.—Electrolytic Survey of Toledo.

station of the electric railways. But these curves can teach a still more important lesson. As they are lines of equal potential, it is evident that any metallic conductor so located as to be essentially parallel to any equipotential curve will lie in a region where there is no electromotive force to cause a flow of current, and consequently will not be subjected to any electrolytic action. On the contrary, if a conductor be so placed as to cut the equipotential lines,

current will flow from the regions of higher potential to those of lower potential, and corrosive action may be expected, the amount of which may be roughly estimated by the number of equipotential lines cut or the steepness of the electrical gradient. To return to the analogy of the topographical map, if a stream were seen to cut a number of contour lines it could be confidentially predicted to be swift, rapid and full of falls, while if parallel to them, slow and sluggish. Though the electrical survey does not entirely take the place of manhole inspection, it presents a view so much wider, more comprehensive and prophetic that it is well worth its small cost. Nor is it sufficient to make a single examination and rest secure in the assumption that the electric potential is forever settled. Figs. 36 and 37 give the results of two electrolytic surveys made of the city of Chicago, one year apart, showing the very marked change in electrical conditions that took place during that interval. To be sure, the period embraced was one of very rapid railway development, so usually the change would be much less marked, but there is always growth of some kind, either new lines are built or old ones extended, or their loading increased; so that here, as in most other instances, eternal vigilance is the price of security, and a careful examination at least once a year should be made.

Having from the electrolytic survey and manhole inspection determined the various situations on the cable system that are in danger, or where there is a tendency for current to leave the cable sheath for the earth, the next step is a selection of a method of protection. *The current must not leave the cable sheath and pass into the*


Map showing
EQUIPOTENTIAL
CURVES
OF THE RETURN CURRENT
TO THE VARIOUS POWER
STATIONS
OPERATING ELECTRIC RAILWAYS
IN CHICAGO ILL.
Key
1 Power Sta. (N Shore Ry. Co.)
2 North Chicago Ry. Co's. Power Sta.
3 Western Ave. Power Sta. (W. Chi. Ry. Co.)
4 Metropolitan Ry. Power Sta.
5 General Ry. Co's. Power Sta.
6 Chicago City Ry. Power Sta.
7 Power Sta. (N. Chicago Ry. Co.)
8 Oakley Ave. Power Sta. (Chi. City Ry. Co.)
Underground Cables Danger Portion
Aerial Cables Conn. with Underg. Cables
Equip. Curves referred to Main Office
Chicago Telephone Co's. Exchanges
LAKE MICHIGAN
MAIN
WEST
HARRISON
CANAL
YARDS
OAKLAND

earth. This is the *only* requisite, and any device accomplishing this result will suffice. It is possible to attack the problem from either end; to prevent current from entering and passing along the cable, or to provide a good way for it to leave the sheath. The first method can be put in practice by insulating portions of the sheath that cut the higher equipotential curves, or those which are more remote from the railway power station. In many cases the simple expedient of cleaning out the manholes and ducts, lifting the cables off the wet floors of the vaults, and supporting them upon insulated pins, driven into the vault walls, will change many electro-positive spots to electro-negative ones and obviate further injury. Sometimes one or two breaks in the continuity of a long cable will prevent the current from following the sheath. Such breaks may be inserted without risk to the insulation of the cable, by making "insulating joints" similar to the one illustrated in Fig. 38. This expedient is of special utility, when cables are partly aerial and partly underground.

The second plan consists in providing each danger spot with a supplementary conductor attached to the cable sheath of a better conductivity than the earth. This is the "*supplementary return feed*" plan, and is usually accomplished by attaching a copper wire of sufficient section to the cable and carrying the same to the railway track if well bonded, or to a railway return feed, or even in extreme cases clear to the power station itself, and attaching it to the negative busbar of the switchboard. Such cases, however, in the present state of railway construction are rare.

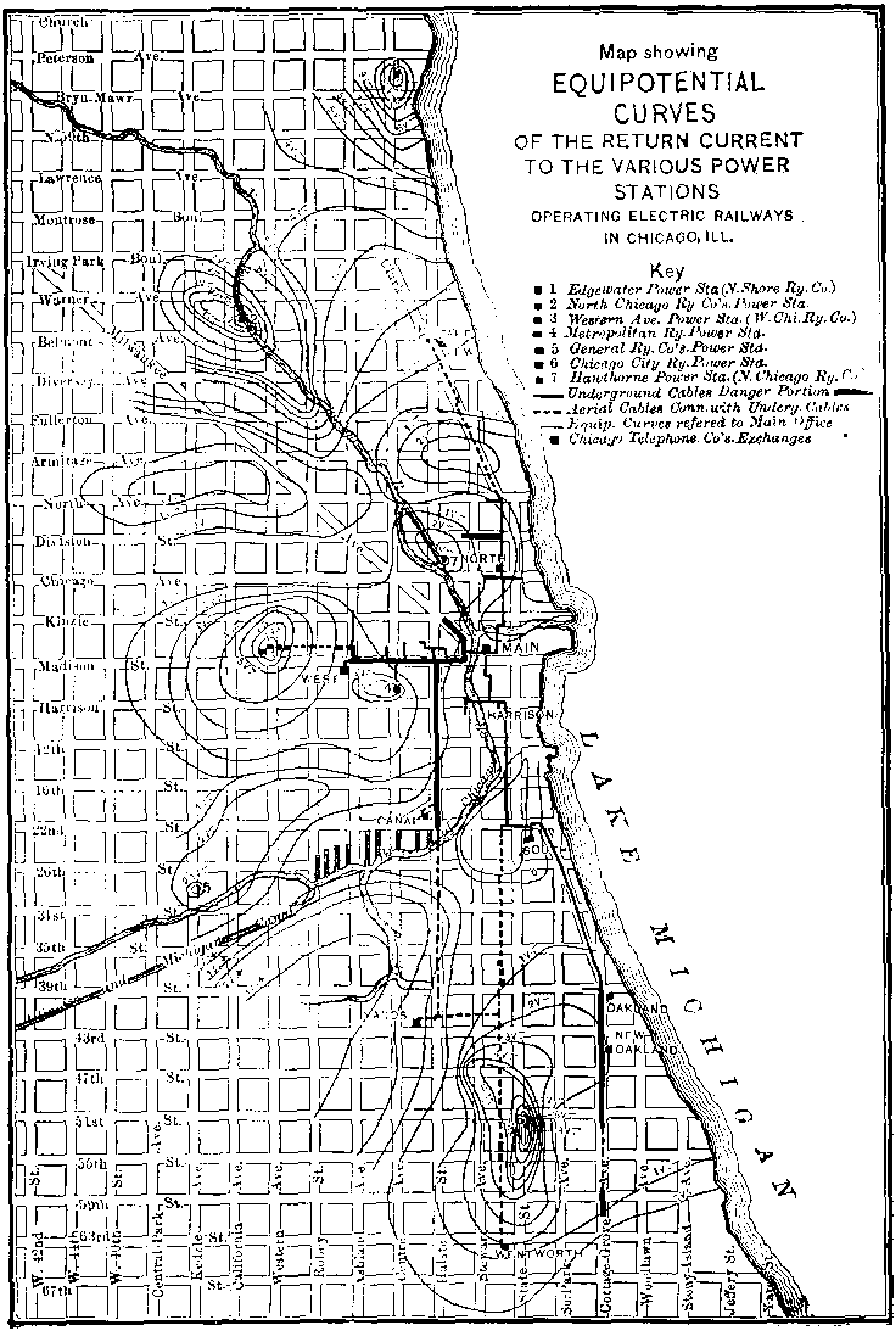


Fig. 37.—A Later Electrolytic Survey of Chicago.

If the current traversing the cable sheath is not large, and the length of the return feeds likely to be considerable, a good ground plate will afford protection. For this purpose a hole four or five feet square should be excavated deep enough to reach a permanently moist stratum of earth. At the bottom a few bushels of coke will form a good medium for delivering current to the earth, in which may be imbedded a lot of old rails, discarded car-

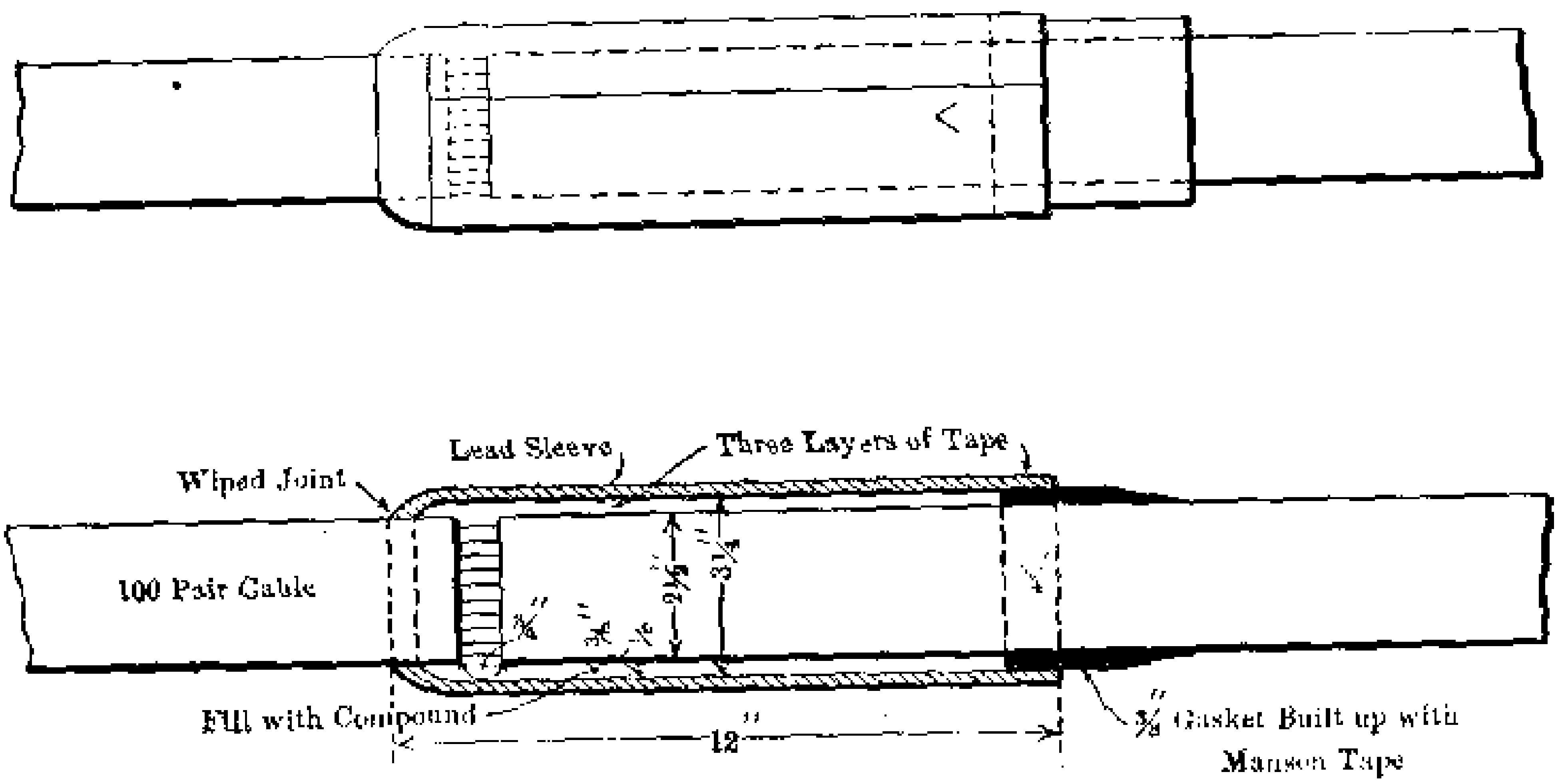


Fig. 38.—Insulated Break for Sheath of Lead-Covered Cables.

wheels, or any metallic scrap. This should be thoroughly tied together with plenty of copper wire, and connected to the cable sheath with an ample lead of copper. The ground plate acts to carry current from the cable to the earth, and diverts the electrolytic action from the sheath to the plate. That corrosion will there take place, and in time destroy the ground plate, is unquestioned, but at reasonable expense the volume of the ground plate can be made so large as to last for many years.

A practical illustration of what the return feed expe-

dient can accomplish may not be amiss. Turning to Fig. 37 a black line will be found extending on Halsted Street from Madison Avenue to Twenty-second Street. This represents a cable run which intersected a number of equipotential curves. Measurements in the various man-

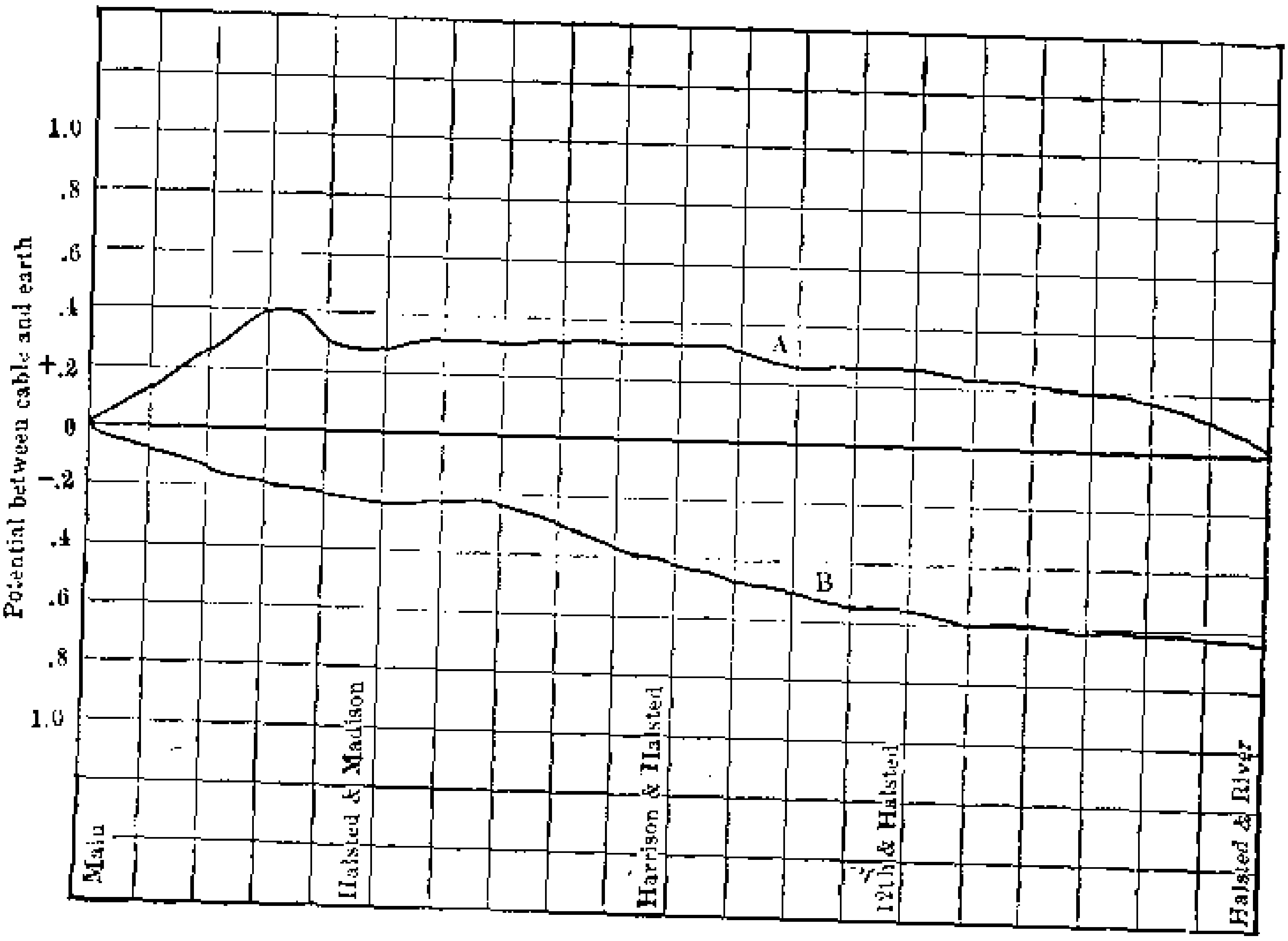


Fig. 39.—Curves Showing Potential Differences Between Cable Sheath and Earth.

holes, indicated the potential differences between the cable sheath and the earth, which when plotted yielded a curve something as shown in Fig. 39 at "A." By connecting the railway track to the sheath at several points, the electrical conditions were entirely changed to that shown by the line marked "B," indicating complete protection from electrolytic action.

CHAPTER V.

COST OF CABLE WIRE PLANT.

THE expense of telephone cables will vary with the prices of lead and copper, the materials of which they are chiefly composed, and with the electrostatic capacity of the completed cable. As different manufacturers use slightly different thicknesses of lead sheath, and as cable for aerial lines is often made with a thinner armor and lighter conductors than that intended for underground service, aerial cables are usually slightly cheaper than those designed for underground lines. Cable prices will also vary, depending upon freight charges from manufacturing centers to the point of consumption.

It is further necessary to allow for cost of splicing and erecting cable either in the ducts, or upon pole lines, and for the cost of terminals. Experience shows the cost of splicing and installing to vary from about 3 cents to about 10 cents per foot, for it is more expensive to splice and erect large fine wire cables than medium-sized, coarse wire ones, and again small cables are more expensive than medium-sized ones. The conductor sizes for all telephone cable are in B. & S. gauge.

Based upon the prevailing prices for copper and lead for 1902, including splicing and erecting expense, the

tabular curves shown in Fig. 40 at *B* are plotted. The lower horizontal axis is devoted to the number of pairs, while the left-hand scale is the price per foot in dollars. Three curves are shown, one for No. 19 gauge, from 10 to 275 pairs; one for No. 20 gauge, from 10 to 400 pairs; and one for No. 22 gauge, from 200 to 400 pairs.

For No. 19 gauge cable the electrostatic capacities assumed are .080 m.f. per mile for sizes from 10 to 150 pairs inclusive. From 150 to 275 pairs, .110 m.f. per mile. For No. 20 gauge cable the capacities taken are .085 m.f. per mile, from 10 to 150 pairs, and .110 m.f. per mile from 150 to 250 pairs, and .115 per m.f. per mile from 150 pairs to 400 pairs. For all No. 22 gauge cable .120 m.f. per mile is predicated.

By turning the sheet of Fig. 40 around four more curves are found, three on the left hand at *A* and one on the right hand at *D*. The curve on the right hand at *D* expresses the percentage relation between the copper cost and the total cable cost. The right-hand scale is in per cent, while the horizontal axis gives the number of pairs, the curve showing for the varying number of pairs, the per cent that the copper cost is of the total cable cost. On the left-hand side three curves are given, showing the weight per foot of the various sizes of cable conductor gauges, Nos. 19, 20 and 22. The left-hand scale is weight per foot, while the horizontal scale gives the number of pairs.

In the nature of telephone business it is impracticable to utilize all of the cable wire which is laid. As the cable extends away from the exchange some wires will be utilized by subscribers nearer to the office than others,

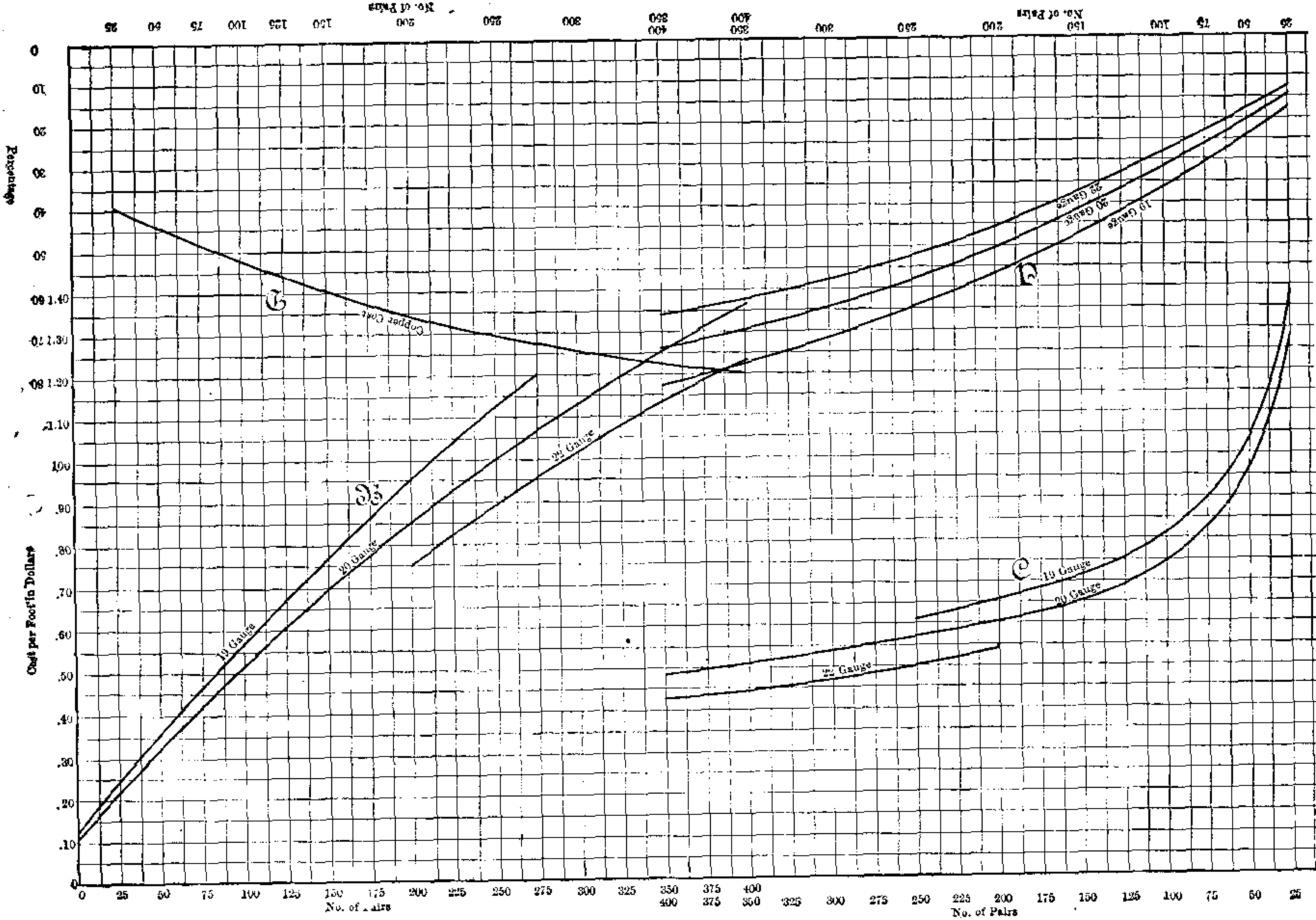


Fig. 40. — Curves Showing Cost of Cable Wire Plant.

thus involving more or less loss of cable conductors beyond. It is impossible for the very best estimate to state exactly the number of conductors needed to serve a given district; moreover from time to time subscribers move from one place to another, thus vacating cable wires in one place and demanding additional facilities at other points. It is in addition always essential to provide a certain surplus of facilities over and above the exact demands of the business, so with the most skillful planning and the best generalship it is impracticable to utilize more than 75 per cent of the cable conductors laid. Thus in estimating the cost per circuit mile of cable wire, allowance must be made for that which is dead, and while it is sometimes possible to utilize three-quarters of the conductors installed it is pretty safe to assert that to-day not over 50 per cent of all cable wire laid is active.

In Fig. 40 three curves are given on the right-hand side of the sheet at *C* to facilitate estimating the cost of wire plant, by giving the probable cost per active pair mile of cable wire, based upon the previously specified percentage of working wires. Three curves are given — one for No. 22 gauge, one for No. 20 gauge, and one for No. 19 gauge. These curves are the reciprocals of the curves upon the left-hand side of the sheet, divided by 75 per cent.

To estimate the gross cost of cable plant it is desirable to know the total expense per mile of cable laid in place. By a similar train of reasoning to that just given for the existence of inactive cable wire, a certain allowance must be made for dead conduit space, and it is usually estimated that not over 70 per cent of all ducts laid are actually available.

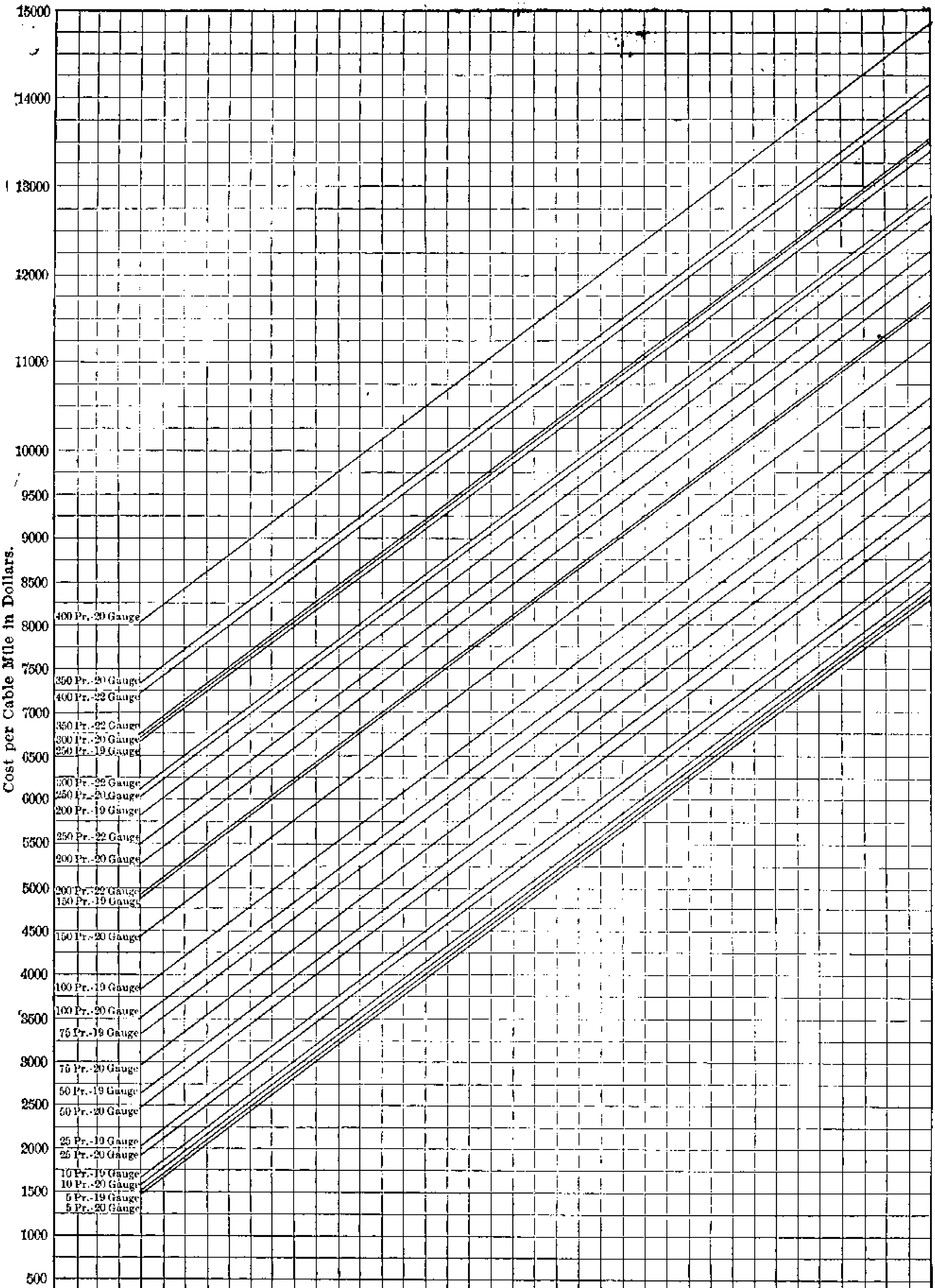
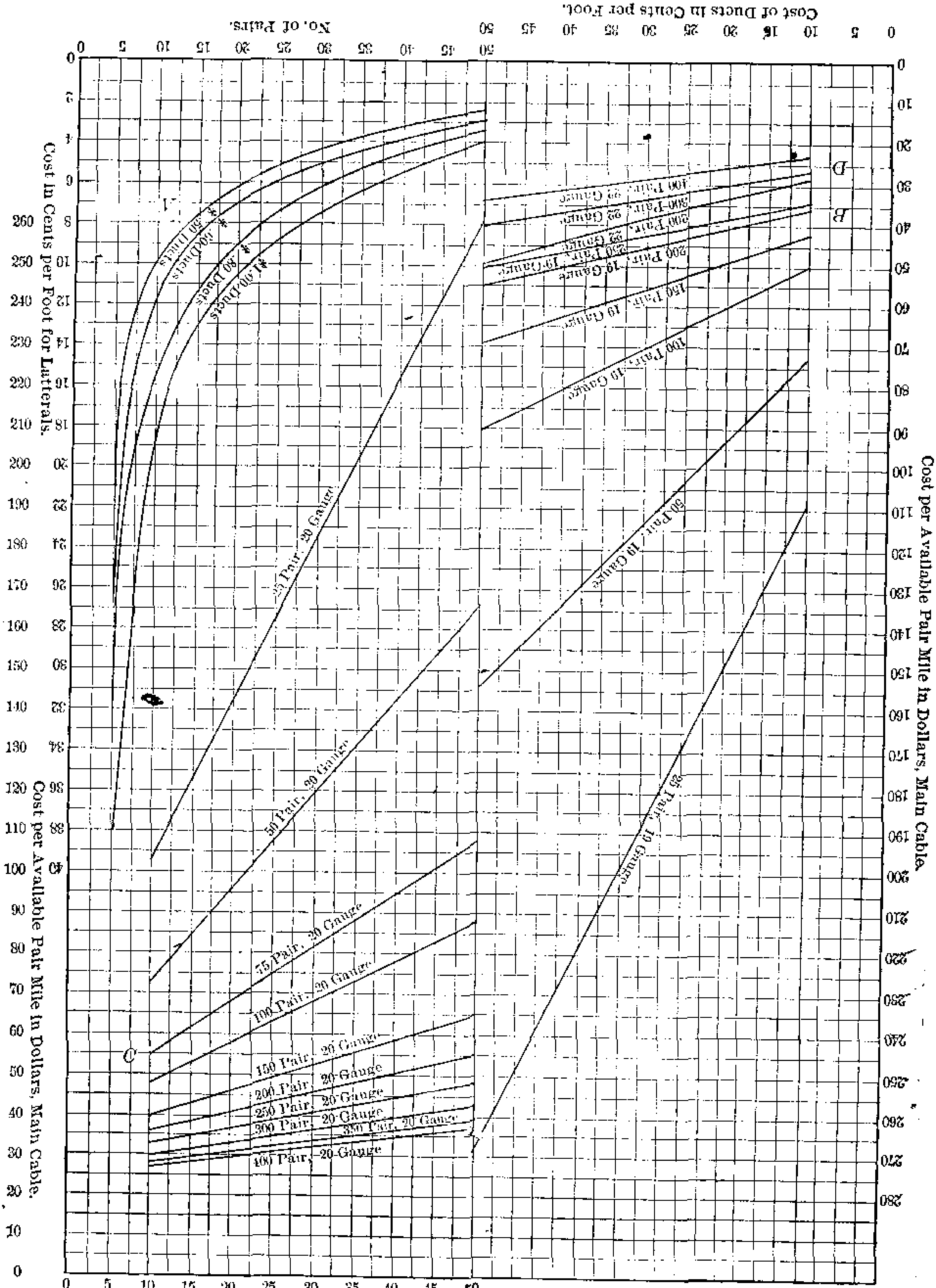

15000
14000
13000
12000
11000
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
Cost per Cable Mile in Dollars.
400 Pr.-20 Gauge
350 Pr.-20 Gauge
400 Pr.-22 Gauge
350 Pr.-22 Gauge
300 Pr.-20 Gauge
250 Pr.-19 Gauge
300 Pr.-22 Gauge
250 Pr.-20 Gauge
200 Pr.-19 Gauge
250 Pr.-22 Gauge
200 Pr.-20 Gauge
200 Pr.-22 Gauge
150 Pr.-19 Gauge
150 Pr.-20 Gauge
100 Pr.-19 Gauge
100 Pr.-20 Gauge
75 Pr.-19 Gauge
75 Pr.-20 Gauge
50 Pr.-19 Gauge
50 Pr.-20 Gauge
25 Pr.-19 Gauge
25 Pr.-20 Gauge
10 Pr.-19 Gauge
10 Pr.-20 Gauge
5 Pr.-19 Gauge
5 Pr.-20 Gauge

Fig. 41 gives graphical data showing the total cost per mile of cable of various sizes installed in conduit, costing from ten cents to $1 per foot, assuming 30 per cent of dead ducts. For each gauge of wire, viz.: Nos. 19, 20 and 22, a curve is given for each size of cable. The horizontal scale shows the varying cost per duct foot, while the vertical scale is the total cost per mile of cable in place exclusive of terminals.

In Fig. 42 a similar set of curves is prepared, showing the cost per active pair mile. The sheet contains three sets of curves. Those at *A* giving the cost per pair foot for No. 19 gauge cable from 5 to 50 pairs installed in ducts, costing 50, 60, 80 cents and $1.00 per foot. This table is valuable in calculating the cost of laterals and terminals, where a cable is taken from the main conduit line and extends to a terminal placed either in a building or on a pole. Usually these lines are short and consequently costs are given per foot of pair circuit. Such lines are always isolated ones and the expense of conduit is very great. The curves at *D* give the cost per active pair mile, for 200, 300 and 400 pair No. 22 gauge cable laid in conduits costing from 10 to 50 cents per lineal foot, as shown on the lower horizontal scale. The curves at *B* give costs of 25, 50, 100, 150, 200 and 250 pair cable No. 19 gauge cable laid in similar conduit. Finally the curves at *C* are similar expressions for cost of cable from 25 pair to 400 pair No. 20 gauge. By means of these three tables an estimate of cost of cable placed under all ordinary conditions of telephone practice, may be readily made, and it is easy to interpolate new rates for any number of pairs between those for which curves are given.



Cost of Ducts in Cents per Foot.
No. of Pairs.
Cost in Cents per Foot for Laterals.
Cost per Available Pair Mile in Dollars, Main Cable.
Cost per Available Pair Mile in Dollars, Main Cable.
A
B
C
D
50 Ducts
60 Ducts
80 Ducts
100 Ducts
400 Pair, 22 Gauge
300 Pair, 22 Gauge
200 Pair, 22 Gauge
250 Pair, 19 Gauge
200 Pair, 19 Gauge
150 Pair, 19 Gauge
100 Pair, 19 Gauge
50 Pair, 19 Gauge
25 Pair, 19 Gauge
25 Pair, 20 Gauge
50 Pair, 20 Gauge
75 Pair, 20 Gauge
100 Pair, 20 Gauge
150 Pair, 20 Gauge
200 Pair, 20 Gauge
250 Pair, 20 Gauge
300 Pair, 20 Gauge
350 Pair, 20 Gauge
400 Pair, 20 Gauge

To the costs thus found must be added the necessary expense for terminals. If plain cable heads be used the cost of the head and splicing will vary from $1.00 per pair for small sizes to 20 cents for large ones. Cable heads equipped with protectors (lightning and sneak current arresters) cost from 20 cents to 50 cents per line in addition. Pot-head splices cost from $2.00 per cable for small sizes (25 pair to 50 pair cables) to 5.00 for the large sizes (50 pair to 400 pair). This includes labor and all materials excepting the flexible terminals. Okonite wire for terminals costs from 2 to 4 cents per pair foot. Silk and cotton switchboard cable, 20 pairs, from 15 to 25 cents per cable foot, while wool cable costs from 75 cents to $1.25 per cable foot for 50 to 100 pairs. The cost of forms for cable heads, distributing board terminals, etc., may be taken at 1 cent to 2 cents per wire. The cost of messenger wire for aerial cables, cable boxes, bridle wires, etc., connecting open wire lines, properly belong to aerial construction, and will be considered thereunder.

The enemy of the paper cable is moisture. Even with the utmost care and in spite of the apparent protection offered by conduit and sheath, underground cables gradually fail. In some cases life is very long, but from one cause and another, owing to extension, necessary rearrangement of plant, etc., a thousand and one causes operate to injure the cable insulation, and deterioration is inevitable and must be provided for in the depreciation account.

For underground main cable from 5 per cent to 7 per cent is a fair annual charge, while for laterals from 8 per cent to 10 per cent is essential. Aerial cable is much

more exposed to injury than underground lines, for it is a constant prey to all sorts of additional destructive forces —sleet and wind storms, lightning, crosses with high potential wires of all kinds; the small boy with a shot gun or rifle, and hundreds of other influences constantly attack it. Moreover, aerial lines have a shorter life than underground ones; as being chiefly erected in districts which are growing rapidly, they are soon superseded by conduit work. For these reasons an allowance from 10 per cent to 12 per cent for depreciation for aerial cables is none too great.

The maintenance to which cable wire is subjected will depend very largely upon the rate of growth in the exchange. Where this is rapid there is a constant necessity for re-arranging and re-modeling cable plant. Under such circumstances maintenance charges will vary from 2 per cent to 5 per cent on the cost of installation. For where growth is slow, and there is but little change in districts, maintenance may fall as low as from 1½ per cent to 3 per cent. With aerial cables 5 per cent for maintenance is the least charge which should be considered. Combining the charges for both depreciation and maintenance the annual expense for underground wire plant should be taken at from 5 to 10 per cent for main cables, from 10 to 15 per cent for laterals, and from 12 to 16 per cent for aerial cables.

CHAPTER VI.

THE CONSTRUCTION OF CABLE PLANT.

THERE is much diversity in the practice of building cable installations. In many cases telephone companies contract with cable maker to supply and install a complete cable plant, and most manufacturers will undertake the entire job. They frequently prefer to, for if cable is sold f. o. b. factory, or cars, or boat, subsequently installed, and then fails, it is a hard question to decide whether the fault lies in the original making or is due to processes in erecting, but if manufacturing and placing are done by one and the same party all the difficulties of divided responsibility are avoided, and matters much simplified. When a large original plant is to be introduced the contract course is decidedly preferable, and the accompanying form of contract and specifications is written as an aid to the prosecution of such construction. But there will be many cases when a telephone company will desire to do its own installation. The plant may be too small to attract contractors, or it may be a case of rearranging an old plant, in a manner that practically precludes a contract. Then the telephone company will simply wish to buy cable. To this end the contract and specifications are so arranged (by the cancellation of occasional phrases)

as to be suitable for either purpose. For either case it is desirable to invite the attention of manufacturers by a letter drawn in the following fashion:

The...................... Telephone Co. is desirous of contracting for the manufacture and delivery at.................................. of about .... feet of telephone cable of various sizes. The cable is to be installed in .... and the contractor is (or is not) requested to bid on the erection. Plans and specifications are inclosed, and any further information may be secured by application to the undersigned. You are requested to submit your proposal not later than .... The company reserves the right to reject any or all bids, or to divide the contract into two or more parts.

......................................*Mgr.*

CONTRACT AND SPECIFICATIONS FOR CABLE CONSTRUCTION.

A CONTRACT AND GENERAL SPECIFICATIONS FOR CABLE MANUFACTURE.

1. Subscribers' Cables.
2. Trunk Cables.
3. Toll Line Cables.

B SPECIFICATIONS FOR SPLICES.

1. Main Cable Splices.
2. Branch Cable Splices.

C SPECIFICATIONS FOR TERMINALS.

1. Cable Head Terminals.
2. Flexible Terminals.

D SPECIFICATIONS FOR INSTALLATION.

1. Underground Cables.
2. Aerial Cables.

(A) *CONTRACT AND GENERAL SPECIFICATIONS FOR THE MANUFACTURE OF TELEPHONE CABLES.*

THIS AGREEMENT made and concluded this ....day of.......................... in the year Nineteen Hundred and.......................by and between the ....COMPANY, organized and existing under the laws of the State of...................... having its principal business office in the City of............ ....State of ....party of the first part and the......................Company, organized and existing under the laws of the State of..........................having its principal office in the City of........................State of ....party of the second part, WITNESSETH:

SECTION 1.

Contract.

That the party of the second part has agreed, and by these presents does agree, with the party of the first part, for and in consideration of the prices and agreements hereinafter stipulated, well and truly paid and performed by the party of the first part, and under penalty expressed in a bond bearing date of......................and hereunto attached, marked Section 38, to manufacture and deliver * and install at his own proper cost and expense each and all of the various sizes, kinds and pieces of telephone cable described in Schedule 1, Section 18, hereunto attached, entirely in accordance with these specifications.

* Cancel "and install" if cable is installed by Telephone Company.

SECTION 2.

Definitions.

All words referring to the respective parties shall be taken of such number and gender as the character of the parties requires.

(*a*) The word "*Company*" shall mean the.................. .... TELEPHONE COMPANY, of .... which has entered into this contract as party of the first part.

(*b*) The word "*Contractor*" shall mean the.................. ....COMPANY, which has entered into this contract as party of the second part.

(*c*) The word "*Inspector*" shall mean the duly appointed representative of the Company, authorized to perform the various tests, inspections and examinations hereinafter specified.

(*d*) The word "*Cable*" shall mean an aggregate of copper wires each electrically insulated from all others and inclosed in a lead sheath or pipe hermetically sealed. Different sizes of cables shall be described by stating the number of pairs of wires which each size contains. The length of each piece shall be specified by stating the number of linear feet it shall contain; hence each separate piece of cable is described by specifying its length in feet and the number of pairs.

(*e*) The word "*Duct*" shall mean a hole, or passageway, or pipe into which a cable may be placed, usually constructed beneath the surface of a street or alley, or in the walls or floor of a building, or along a pole of an aerial line.

(*f*) The word "*Manhole*" shall mean any chamber or space giving access to ducts.

SECTION 3.

Description.

The work called for in this contract and specification is as follows:

(*a*) The supply of all necessary material, labor, tools, and appliances to manufacture, pack, ship, transport and deliver f. o. b. cars or vessel, in the City of .... each and every piece of cable enumerated in Schedule 1, Section 18, of this indenture. The various pieces of cable scheduled shall be made and delivered in the order specified in this schedule, in Column 6, headed "*Date of Delivery.*"

If, prior to the completion of the manufacture of the cable enumerated in Schedule 1, Section 18, the Company shall elect to increase any or all of the amounts of cable called for in said Schedule, it shall have the right to make any such increase in any or all sizes. For all such additions the company shall pay the same price per linear foot for each size as is specified in Schedule 1, Section 18, at the time of the execution of this contract.

* (*b*) As fast as the cable reaches the City of .... the Contractor shall proceed to install each and every piece of cable in the places specified in Schedule 1, Section 18, in Column 9, headed "Location." The location of each piece of cable is specified by stating in Column 7 opposite each piece whether it is to be placed in under-

* Cancel (*b*) if cables are installed by the Company.

ground conduit, or on an aerial line, and in Column 9 the name of the street, alley, or other location along which it is to extend, and the terminal points between which it is to be placed. Column 8 specifies the terminal to which each end shall be connected. After each piece is installed in its proper place it shall be spliced by the Contractor to any and all adjoining pieces, or connected to an appropriate cable head or heads or other terminal or terminals as specified in Column 8 of Schedule 1. If one or more cable heads are used at any point to terminate a piece of cable, the heads shall be supplied by.......................... but the Contractor shall, at his own proper cost and expense, supply all labor and materials to properly join the cable to the head or heads.

SECTION 4.

Power of the Inspector.

(*a*) During the manufacture of each and every piece of cable herein called for the Inspector shall have the right to examine all materials used, and test the same as hereinafter specified, and to inspect the workmanship employed, and to test as hereinafter provided, each finished piece of cable. In case any material shall fail to meet any or all the requirements, or any workmanship shall be defective, or any finished piece of cable shall not fulfill any or all of the tests hereinafter provided, the Inspector shall reject the same. The Company may, at its option, make the final tests on the finished cable either at the works of the Contractor at..............or after delivery of the Cable in the City of......................

* (*b*) After each piece of cable is installed in its place, as specified in Schedule 1, Section 18, and finally spliced or otherwise connected to the terminals specified, the Inspector shall examine and test the same as hereinafter specified.

SECTION 5.

Access to Work.

The contractor shall at all times afford the Inspector all facilities to examine, inspect and test all materials, processes, machinery, finished cable and cable laid in place, and all opportunities to satisfy himself of the skill and competency of all men employed.

SECTION 6.

Orders to Contractor.

Whenever the contractor is not present in person, when it may be necessary to give any instructions regarding the work herein called for, such directions as may be given by the Inspector shall be received and obeyed by the Foreman, or other persons in charge.

SECTION 7.

Legal Authority.

The necessary legal authority to work in and occupy the Streets of the City of....................shall be obtained by the Company and delivered to the contractor in the form of such written permits as may be necessary and customary

* Cancel (*b*) if cable is installed by the Company.

in said City. If after the receipt of said permit the contractor shall allow the same to be lost or destroyed, the Company shall, on written notice from the contractor, take out a new permit and shall charge against the contractor all necessary expense thereof.

SECTION 8.

Obedience to Law and City Regulations.

In all operations in any way connected with the work herein specified the contractor shall comply in all respects with all the laws of the land and all city rules and regulations affecting in any way the conduct of those engaged, or the methods of doing any or all parts of the work, or in the use of materials, tools, appliances, or machines.

SECTION 9.

Responsibility of Contractor.

During the progress of all parts of the work herein called for the contractor shall take all precautions, and shall assume all responsibility of whatsoever nature for the prevention of any and all injuries to any person whatsoever, whether employed by the contractor or not. He shall and does hereby assume all responsibility and liability for any injury of whatsoever nature to any persons or property, and shall and does hereby assume all liens, suits, or claims for damages, either to life, limb, property or person, arising from any act or omission, or from the amount or character of the work, or in the way in which it is done, and shall and hereby agrees to save harmless the Company, its officers and agents, for all claims relating

to any damage or injury actual or consequential, present or future.

SECTION 10.

Competent Men and Suitable Tools.

The contractor shall only employ competent and orderly artisans, thoroughly familiar with the work to which they are assigned. If, in the opinion of the Company, any men are employed who are incompetent or disorderly, the Company shall notify the contractor thereof and he shall forthwith remove them from the work. The contractor shall constantly supply and maintain any and all necessary and suitable tools, machinery, appliances and material that shall be sufficient to prosecute each and every part of the work at such a rate of speed as shall ensure in the completion thereof within the time specified in Section 13.

SECTION 11.

Company's Right to Assume Work.

If any portion of the work herein specified shall be abandoned, or if in the opinion of the Company any of the provisions of this contract shall not be fulfilled, particularly those of Section 10, or any part shall be unnecessarily delayed, the Company may notify the contractor to discontinue all or any part thereof, and the Company may by contract or otherwise complete the work, or any part thereof, and charge any and all expense of such completion to the contractor. The expense so charged shall be deducted and paid by the Company out of any moneys then due, or to become due, the contractor. In case such

expense is less than the sum which would have been payable under this contract if the same had been completed by the contractor, he shall be paid the difference; but in case such expense shall exceed the latter sum, the contractor shall, on demand, pay such excess to the Company.

SECTION 12.

Acceptation.

*1. As fast as the cable is received in the City of ....the Inspector shall inspect and examine it, and if the Company shall so elect, shall test the same as hereinafter provided. For all cable which entirely fulfills each and every provision of the specification the Inspector shall, as soon as inspected and accepted, issue a certificate of inspection to the contractor. On the issuance of this certificate the cable therein specified shall pass to and become the property of the Company, and the responsibility of the contractor therefor shall end. All cable which does not fulfill each and every provision of the specification shall be rejected by the Inspector, and shall remain the property of the contractor. All cable which is rejected shall be replaced by that which shall fulfill all the provisions of the specification.

†2. After each piece of cable is installed, spliced, and terminated, as specified in Schedule 1, Section 18, and entirely ready for operation, the Inspector shall test, inspect, and examine the same, as hereinafter provided. For all cable which fulfills all the provisions of this speci-

* Cancel (1) if installation is done by contractor.

† Cancel (2) if installation is done by Company.

fication and which is installed in a manner acceptable to the Inspector, properly spliced and terminated, the Inspector shall issue a certificate of acceptance to the contractor. On the issuance of this certificate the cable shall pass to and become the property of the Company, and the contractor shall be no longer responsible therefor. Any cable which fails to fulfill any of the specification requirements, or which is improperly installed, spliced, or terminated, shall be rejected by the Inspector and shall be at once removed by the contractor and replaced by cable which is in accordance with all the provisions of the specification and is properly and acceptably installed, spliced, and terminated.

SECTION 13.

Time of Completion.

(*a*) The contractor hereby agrees to commence manufacture within..................days from the date of this contract, to commence to deliver the cable called for f. o. b. cars or boat in the City of......................on or before the ....day of......................and to continue to deliver the cable in said City f. o. b. cars or boat at the rate of................feet each and every week thereafter until the entire amount called for in Schedule 1, Section 18, shall be so delivered.

*(*b*) The contractor agrees to commence the installation of cable on the.....................day of.....................and to complete the installation of all the cable herein called for within......................days thereafter. Sundays and legal holidays excepted.

* Cancel (*b*) if installation is done by the Company.

SECTION 14.

Damages for Delay in Completion.

In case the contractor shall fail to complete the entire amount of the work herein specified within the time called for in Section 13, the Company shall have the right to deduct and retain out of the moneys which may be due or may become due the contractor under this contract, the sum of..................dollars as liquidated damages for each and every day that the entire work herein specified shall remain uncompleted over and above the time specified in Section 13, Sundays and legal holidays excepted.

SECTION 15.

Liens on the Work.

Upon the completion of the work and before final payments are made to the contractor he shall file with the Company suitable evidence that all causes of action for damages, and all liens have been by him entirely liquidated, released and satisfied and he shall furnish to the Company a clear title to each and all parts of the work.

SECTION 16.

Extra Work.

The contractor shall do no work, nor supply any materials of any nature not herein provided for, unless authorized by a separate and supplemental contract in writing with the Company, nor shall the contractor make any claim of any nature whatsoever for the payment of any moneys except as provided for in Section 18.

SECTION 17.

Conditions of Payment.

Between the 1st and 5th days of each calendar month the Inspector shall render to the Company a *Certificate of Estimate*, stating the number of linear feet each kind of cable specified in Schedule 1, Section 18, that have been tested, inspected and found in all respects to have fulfilled all provisions of this contract and specifications, and shall give the contractor a copy of the same. This certificate shall also state the amount of the contract price of the cable thus tested and inspected, calculated by the prices set opposite each kind of cable in Schedule 1, Section 18. Within ten days after the rendering of the certificate of estimate the Company shall pay to the contractor.................per cent of the amount called for in the certificate of the Inspector and shall reserve and retain ....per cent thereof until the completion of the entire work.

2nd. On the entire completion of all the cable called for in Schedule 1, Section 18,* and the complete installation of the same, and on final inspection and acceptation of the same by the Inspector as herein provided, and upon full performance in all other respects of this contract the Inspector shall so certify to the Company. Within thirty days thereafter the Company shall make to the contractor a final payment, which shall include all balances which have been reserved from the preceding monthly payments.

* Cancel "and the complete installation of the same," if installation is done by the Company.

SECTION 18.

Prices for Work.

The Company shall pay as full compensation for each and every lineal foot of each size of cable delivered and accepted by the Inspector, and for everything done and furnished under this contract, including all damage arising out of the nature of the work, or from the action of the elements, and all risks of every description connected therewith, and for all expenses entailed in consequence of the suspension or discontinuance thereof the amounts per linear foot for each size of cable that are set in Column 10, headed "*Price per Linear Foot*" of Schedule attached to this Section marked *Schedule* 1, *Prices to be paid per Linear Foot of Cable.* The lengths specified in Schedule 1, Column 4, shall be the distances measured along the conduit or pole lines of the Company, and shall not include any allowance for splicing or terminating cable, but shall include necessary amount for slack. The contractor shall make on each end of each piece of cable the necessary allowance for the splice or terminal, as specified in Column 8, and shall make no change for any cable used for this purpose.

SECTION 19.

General Cable Specification.

(*a*) The cable called for under these specifications is that known as "Patterson, Dry Core" or "Paper Cable." Each piece shall consist of a certain number of copper wires, each one insulated from all others by a loose wrap-

SCHEDULE I.

1	Size of Cable in Number of Pairs for Each Piece.		
2	Gauge of Conductors, B. & S.		
3	Electrostatic Capacity in Mf. per Mile.		
4	Length in Feet of Each Piece.		
5	Designation of Each Piece.		
6	Date to be Delivered.		
7	Use Aerial or Underground.		
8	Kind of Terminal at	End A.	
		End B.	
9	Location Where Cable is to be Installed.	On	
		From	
		To	
10	Prices per Linear Foot.	Delivered F. O. B. Cars or Boat in City of	
		For Installing and Terminating.	
		Total Ready for Operation.	

ping of paper. The wires shall be twisted together in pairs, and then a sufficient number of pairs to aggregate the total number required in each size of cable, shall be twisted together or "cabled" into a rope or "core." This core shall then be inclosed in a lead pipe. Cable shall be designed for either of the following purposes:

(1) Subscriber's Cable; namely, that to connect subscribers with central office.

(2) Trunk Cable; that used to connect central offices together.

(3) Toll Line Cable; that used in the construction of "Toll" or so-called "Long Distance Lines."

This contract calls for the manufacture and delivery* and erection of

Subscriber's Cable.
†Trunk Cable.
‡Toll Line Cable.

SECTION 20.

Marking and Packing.

Each piece of cable shall be marked on each end by means of a metal tag upon which the designating number, according to Schedule 1, Section 18, Column 5, shall be stamped. The tags may be affixed to the ends of the cable in any manner to be readily legible, and secure from accidental removal during transportation and installation. Excepting in the case of short lengths, only one piece of

* Cancel "and erection," if erection is done by the Telephone Company.

† Cancel "Trunk Cable" and "Toll Line Cable" if Subscriber's Cable only is desired.

‡ Cancel "Toll Line Cable" if only Subscriber's and Trunk Cable is desired.

cable shall be placed on a reel. At least eighteen (18″) inches of each end of every piece of cable shall be so disposed on the reel as to be readily accessible for testing without uncoiling or removing any cable.

SECTION 21.

Shipping.

As fast as cable is completed at the factory of the contractor, the Inspector shall test the same, provided the company elect so to do, under Section 4. All cable accepted shall immediately after acceptance be carefully coiled on proper reels, so boxed as to prevent injury during transportation, and promptly shipped.

If the Company shall elect to make acceptance tests in the City of..................as provided for in Section 4, the cable shall be reeled, boxed and shipped as above specified, as fast as it is manufactured.

SECTION 22.

Conductor Material.

All conductors for all cable shall be of first-class *soft-drawn* copper wire. The wire shall be true and round, and full to the gauges specified. All wire shall be free from all slivers, nicks or other imperfections. Each size of wire shall be capable of standing not less than sixty twists in a length of two inches. This test shall be applied by a standard wire torsion testing machine. All wire shall have a resistance of at least 98 per cent of pure soft copper, Matthiessen's standard, and shall be drawn

in as long lengths as possible. Necessary splicing shall not be done by twisting or soldering, but by electrical welding. The various sizes of wire shall have diameters, resistances and weights per mile, not less than those specified in Table I.

TABLE No. I.

Diameters, Weights and Resistances of Cable Conductors per Mile.

Gauge No. B. & S.	Diameter in Mils.	Resistance in Ohms.	Weight in Pounds.
10	101.890	5.2773	165.98
14	64.084	13.3405	65.658
17	45.257	26.7885	32.786
18	40.303	33.7285	25.970
19	35.890	42.5329	20.594
20	31.961	53.6362	16.331
22	25.347	85.2743	10.272

SECTION 23.

Insulation.

Each conductor shall be insulated from all other conductors by a continuous wrap of paper. The contractor may use either one or more wraps of paper at pleasure, provided that the subsequent provisions for electrostatic capacity and insulation shall be rigidly maintained. The paper used shall be a first-class quality; it shall be completely free from all substances which might exercise any injurious action upon either the conductors or the sheath. The paper shall be about four mils in thickness and of sufficient strength so that a piece of 1″ wide shall support a weight of not less than 2 lbs. per mil of thickness.

Each individual conductor shall be wrapped with the

paper in such a manner as to completely isolate electrically each wire from every other one and the sheath. Pains shall be taken to make this wrapping as loose as possible, in order that electrostatic capacity may be reduced to a minimum. Prior to wrapping, all paper used shall be kiln dried at a temperature of about 225° F., and completely freed from moisture. The method of cable making shall be such that the paper is placed on the conductors and the conductors promptly twisted, cabled and inclosed in the sheath (and if necessary, subsequently dried), the entire process being so conducted as to ensure the paper being perfectly dry when the cable is completed.

SECTION 24.

Test Wires.

In each piece of cable called for, one extra pair of wires over and above the number specified in Schedule 1, Section 18, shall be introduced for purposes of testing.

SECTION 25.

Coloring of Insulation.

One pair of wires in each piece of cable shall have one conductor covered with paper colored blue, and the other insulated with paper colored white or gray. All of the remaining pairs shall have the insulation of one wire colored red and the other colored white or gray. The blue paper is to designate the test pair of wires.

SECTION 26.

Twisting and Cabling.

Each pair of conductors shall be twisted together in such a manner that the length of the twist shall not exceed 3″ for wire of No. 19 gauge, or over 6″ for wire of No. 17 to No. 19 gauge, and 14″ for wire of No. 10 to No. 14 gauge. All pairs shall then be formed into a cylindrical core, arranged in alternately reversed layers and spiraled about one central pair with a twist, not to exceed one turn in 24 inches.

SECTION 27.

Sheath.

The core of each cable shall be inclosed in a pipe made of (1) pure lead, and after the core is inclosed the cable shall be passed through a bath of melted tin, so applied as to give the exterior a continuous and uniform coating of tin. (2) Lead tin alloy containing about three per cent of tin, in no case less than 2.85 per cent.* On completion the sheath shall be absolutely tight and free from all cracks, blow holes, pin holes or other defects of every nature. In case the Inspector shall suspect imperfections in the sheath, the contractor on demand shall seal one end of the cable and apply an air pressure of not over 75 pounds per square inch of dried air to the other end, and while this pressure is applied the cable shall be drawn through a tank of water, not less than 18 feet long, in order to detect any defects in the sheath. If any defects in the sheath exist they will be made manifest by escaping

* Cancel either (1) or (2) as may be agreed at execution of contract.

air, and shall be remedied; or if, in the opinion of the Inspector, this is impractical, the cable shall be rejected. When presented to the Company for acceptance the sheath shall be sound in all respects, uniform in thickness and composition; shall be round and true and free from all kinks, flat places or other defects. The thickness of the sheath shall not be less, nor the external character of the completed cable more, than the dimensions specified in Table No. II.

TABLE No. II.

Minimum Thickness of Cable Sheath and Maximum Outside Diameter of Cable.

Number of Pairs.	Thickness of Sheath.		Diameter, Inches, Maximum.
	Aerial, Inches.	Underground, Inches.	
5	$\frac{3}{64}$	$\frac{1}{16}$	$\frac{5}{8}$
10	$\frac{3}{64}$	$\frac{1}{16}$	$\frac{13}{16}$
25	$\frac{5}{64}$	$\frac{3}{32}$	$1\frac{5}{16}$
50	$\frac{3}{32}$	$\frac{7}{64}$	$1\frac{3}{4}$
100	[illegible]	$\frac{1}{8}$	2
120	. . . . .	$\frac{1}{8}$	$2\frac{1}{8}$
150	. . . . .	$\frac{1}{8}$	$2\frac{1}{4}$
200	. . . . .	$\frac{1}{8}$	$2\frac{3}{8}$
250	. . . . .	$\frac{9}{64}$	$2\frac{1}{2}$
300	. . . . .	$\frac{5}{32}$	$2\frac{5}{8}$
400	. . . . .	$\frac{5}{32}$	$3\frac{3}{4}$

SECTION 28.

Sealing.

As soon as manufacture is complete the end of each piece of cable shall be sealed for a distance of not less than 2 feet by boiling in melted paraffine and the sheath hermetically soldered over the end.

* SECTION 29.

Receipt of Cable.

(1) On receipt by the Company of customary freight invoice, showing the arrival of each piece and every piece of cable, in the City of......................the Company shall receive, suitably care for, and store the same.

SECTION 30.

Tests.

By Section 4 the Company may at its option test the *completed* cable either at the works of the contractor or on its arrival in the City of...................... † or after it is installed ready for use. The tests shall consist in measuring the conductor resistance, insulation resistance and electrostatic capacity of every wire in each piece of cable, and in testing each pair of wires against every other pair for cross-talk. The method to be used for measuring conductor resistance shall be that known as the Wheatstone Bridge method. The method of measuring insulation resistance shall be either that known as *Direct Deflection*, employing a galvanometer, having a sensitiveness of not less than 750 megohms, or the method of Loss of Charge.

For the measurement of capacity each wire shall be compared by direct deflection (using a galvanometer, as above specified) with a standard condenser, adjusted to

* Cancel Section 29 if Cable is installed by contractor.

† Cancel "or after it is installed ready for use," if installation is done by Company.

approximately the same capacity as the piece of cable under test. All apparatus used in cable inspection shall be that of well-known standard makers. In case any question as to the result of any test shall arise the accuracy of the apparatus shall be verified by sending it to any of the well-known electrical laboratories for comparison.

For the measurements of conductor resistance a battery giving not less than 10 nor more than 100 volts shall be employed. To measuring insulation resistance and capacity a battery giving not less than 200 nor more than 500 volts shall be employed.

Tests for cross-talk shall be made by providing a sound-proof inclosure, such as a regular telephone booth, of such nature that an observer located therein cannot hear any sound from conversation carried on in a very loud tone of voice, or shouted, on the exterior. The booth shall be provided with two standard double-pole receivers similar to those supplied by the Company to its regular subscribers, and from each of these receivers a twisted pair of rubber-covered wires shall be carried outside of the booth, each wire being terminated in a binding post, set on a rubber plate, secured to the outside of the booth. A standard transmitter, with proper battery and all other appliances, and receiver, similar in all respects and wired on the same circuit as regularly supplied by the Company to its subscribers, shall be provided, so arranged that one end of any cable pair may be readily connected to the transmitter and the other to the receiver. A second pair shall be taken and one of its ends connected to one of the receivers, located inside the above specified booth, and the other one to the other receiver. The inspector entering the booth

shall listen with both ears, one to each receiver, while an assistant shall talk into the above specified transmitter in a tone of voice about 50 per cent louder, as nearly as can be estimated, than that used in ordinary telephone connections. If the Inspector can hear no sound under these circumstances he shall accept the cable for cross-talk test. If he can hear any sound, but fail to distinguish articulate sounds, he may accept or reject the cable at his discretion. If he can understand conversation he shall reject the cable unqualifiedly and without appeal. The Inspector shall in this manner test each pair against each other pair, or as many pairs against as many other pairs as he may deem fit. All testing apparatus shall be supplied by the Company, but the contractor shall supply all labor that may be needed by the Inspector in making tests.

SECTION 31.

Requirements.

1. Conductors.

Each conductor shall be continuous from end to end of each piece and shall meet all the requirements of Section 22 and Table No. I. therein contained.

2. Insulation.

Every wire shall have an insulation resistance, after an electrification of one minute, of not less than 5,000 megohms per mile, before it is installed and connected to terminals. After any cable is installed and connected to

terminals every wire therein shall have an insulation resistance of not less than 1,000 megohms per mile.

3. Electrostatic Capacity.

The electrostatic capacity of the various kinds of cable herein called for are specified in Tables Nos. III., IV. and V., Section 32. It is further specified that no one wire shall vary more than 12 per cent from the capacities specified and that the average of all wires in each piece of cable shall not vary more than 7 per cent from the amounts specified in this table.

SECTION 32.

Kinds of Cable.

The properties of the various kinds of cable herein called for are specified in Tables Nos. III., IV. and V.

TABLE No. III.

Number of Pairs, Conductor Gauge and Electrostatic Capacity per Mile of Subscriber's Cable.

No. of Pairs.	Conductor Gauge, B. & S.	Capacity, Mf.	Conductor Gauge, B. & S.	Capacity, Mf.	Conductor Gauge, B. & S.	Capacity, Mf.
10	19	.080	20	.085	. . .	. . .
25	19	.080	20	.085	. . .	. . .
30	19	.080	20	.085	. . .	. . .
50	19	.080	20	.085	. . .	. . .
100	19	.080	20	.085	. . .	. . .
150	19	.080	20	.085	. . .	. . .
200	19	.110	20	.110	. . .	. . .
250	19	.110	20	.110	22	.120
300	. . .	. . .	20	.115	22	.120
350	. . .	. . .	20	.115	22	.120
400	. . .	. . .	20	.118	22	.120

TABLE No. IV.

Number of Pairs, Conductor Gauge and Electrostatic Capacity per Mile of Trunk Cable.

Number of Pairs.	Conductor Gauge, B. & S.	Capacity Mf.	
50	17	.065	.060
75	17	.065	.060
100	18	.075	.075

TABLE No. V.

Number of Pairs, Conductor Gauges and Electrostatic Capacities Per Mile of Toll Line Cable.

Size and Number of Pairs.	Conductor Gauge, Brown & Sharpe.	Capacity.
10	10	.040
20	14	.050

SECTION 33.

Defective Cable.

(1) If any piece of cable shall show cross-talk as specified in Section 30 it shall be unqualifiedly rejected. In case any piece of cable shall in any other respect fail to fulfill any of the tests herein prescribed (except that for cross-talk) the Inspector shall notify the contractor of such failure. In case the contractor desires he may endeavor to repair the cable and may present the same for a second test, and if the cable shall fulfill all provisions of this specification upon second test, the Inspector shall accept same. If, on second inspection, any wire in the cable

fails to meet any of the specification requirements, the Inspector shall either finally and unqualifiedly reject the cable or specifically report it, at his discretion, as hereinafter provided, and the contractor shall not present this piece of cable for a third examination, and he shall at once remove the same at his own expense from the care of the Company and replace it with cable which does fulfill all of the specification requirements.

* (2) After each piece of cable is laid in its place, spliced and connected to the terminals as specified in Schedule 1, Section 18, the Inspector shall measure and test it as hereinbefore provided. If the cable shall fulfill all the provisions of this specification the Inspector shall accept the same. If it shall show cross-talk, as specified in Section 30, it shall be unqualifiedly rejected. If any wire fails to fulfill any other of the provisions the Inspector shall reject the cable. If, after inspection, the contractor so desires, he may endeavor to repair the cable and may present the same for a second inspection. If, on second inspection, all the wires in the cable shall fulfill each and all provisions on this specification the Inspector shall accept it; but if, on second inspection, any wire fails in any particular, the Inspector shall finally reject the cable or specifically report it, at his discretion, as hereinafter provided, and the contractor shall remove the same and replace it with cable which does conform with all provisions of this specification.

(3) In case the Inspector shall find any cable in which a few of the conductors (not to exceed 10 per cent of the entire number) shall slightly fail in some single respect to

* Cancel (2) if cable is installed by the Company.

meet all the test requirements of this specification he may at his discretion make a special report to the Company reciting all the facts relating to the defective cable. If the Company, on receipt of this special report, shall so elect it may accept such piece or pieces of cable. If the Company shall so elect to accept any such defective cable it shall be at liberty to deduct from the contract price specified in Schedule 1, Section 18, such a percentage of the amount that would, if the cable were perfect, be paid therefor, as the sum of the defective wires is of the total wires in the cable.

SECTION 34.

Mechanical Properties.

Each cable shall be so manufactured that it can, without injury to the conductors or the sheath, be coiled and uncoiled at least ten times round a drum, or sheave, having a diameter of not more than twenty times the diameter of the cable, and shall have sufficient mechanical strength so that, if handled with reasonable care by those skilled in the art, it shall be able to retain its cylindrical form during handling and other processes required for erection in place.

SECTION 35.

Installation.

In case the installation of the cable shall be done by the contractor, he shall proceed to do all the work of erecting the various pieces of cable called for in Schedule 1, Section 18, at the places specified in column 9, headed "Location," of Schedule 1, and in the manner and by the

methods of specifications B, C and D, which are attached to this indenture and are hereby made a part thereof.

SECTION 36.

Guarantees.

The contractor shall guarantee that the insulation resistance of each piece of cable shall not decrease below 500 megohms per mile, nor shall the electrostatic capacity increase over the amounts specified in Tables III., IV., or V., Section 33, for a period of two years from the date of this contract, unless due to manifest mechanical injury to the sheath of the cable. As surety for the faithful performance of this guarantee the bond designated as Section 37 shall remain in force for the above specified two years.

SECTION 37.

Execution.

IN WITNESS WHEREOF the parties to these presents have caused the same to be signed by their respective executive officer and their respective corporate seals to be hereto affixed the day and year above written.

(Signature first party)

....

....

(Signature second party)

....

....

(Witnesses)

....

....

SECTION 38.

Bond.

KNOW ALL MEN BY THESE PRESENTS THAT WE.................................. ...as principal, and we..as surety...are held and firmly bound unto the.................................COMPANY, of ....in the sum of..........................dollars, to be paid to the said....... ....COMPANY, its successors and assigns, for which payment well and truly to be made we bind ourselves, our heirs, executors, administrators and successors jointly and severally by these presents.

Sealed with our seal and dated at this........................ day of........................., 19....

THE CONDITION OF THE ABOVE OBLIGATION IS SUCH THAT

Whereas the said above bounden..........................has entered into a certain agreement of................date herewith in which the............................is party of the first part, and the said..............................is the party of the second part, for the full terms used and particulars hereof express reference is hereby made to such agreement, and by this reference it is made a part hereof, to which this bond is annexed.

NOW THEREFORE, if the said.....................shall in all things fully and faithfully keep and perform said

agreement and each and every term and part thereof, then this obligation shall be void, otherwise it shall remain in full force.

WITNESS OUR NAMES AND SEALS.

....Seal.
....Seal.
....Seal.

(Witnesses)
....
....
....

(B) *SPECIFICATIONS FOR CABLE SPLICES.*

1. MAIN CABLE SPLICES.

SECTION 39.

General Method.

Splices in paper cable shall be made by stripping the sheath from one end of each piece to be joined for a distance of from 12″ to 20″, depending on the size of the cable, removing the paper insulation from each wire of each piece for about an inch, twisting each red-colored wire of *one* cable to a corresponding red wire in the *other*, twisting each white wire in one piece in a similar manner, to a white one in the other piece, protecting each wire joint with a paper sleeve, replacing the removed sheath with a lead sleeve wiped to the sheath of each cable, boiling out the completed joint in paraffine, and soldering the holes left in the sleeve to allow of boiling. The general method of making a splice is shown in Fig. 43.

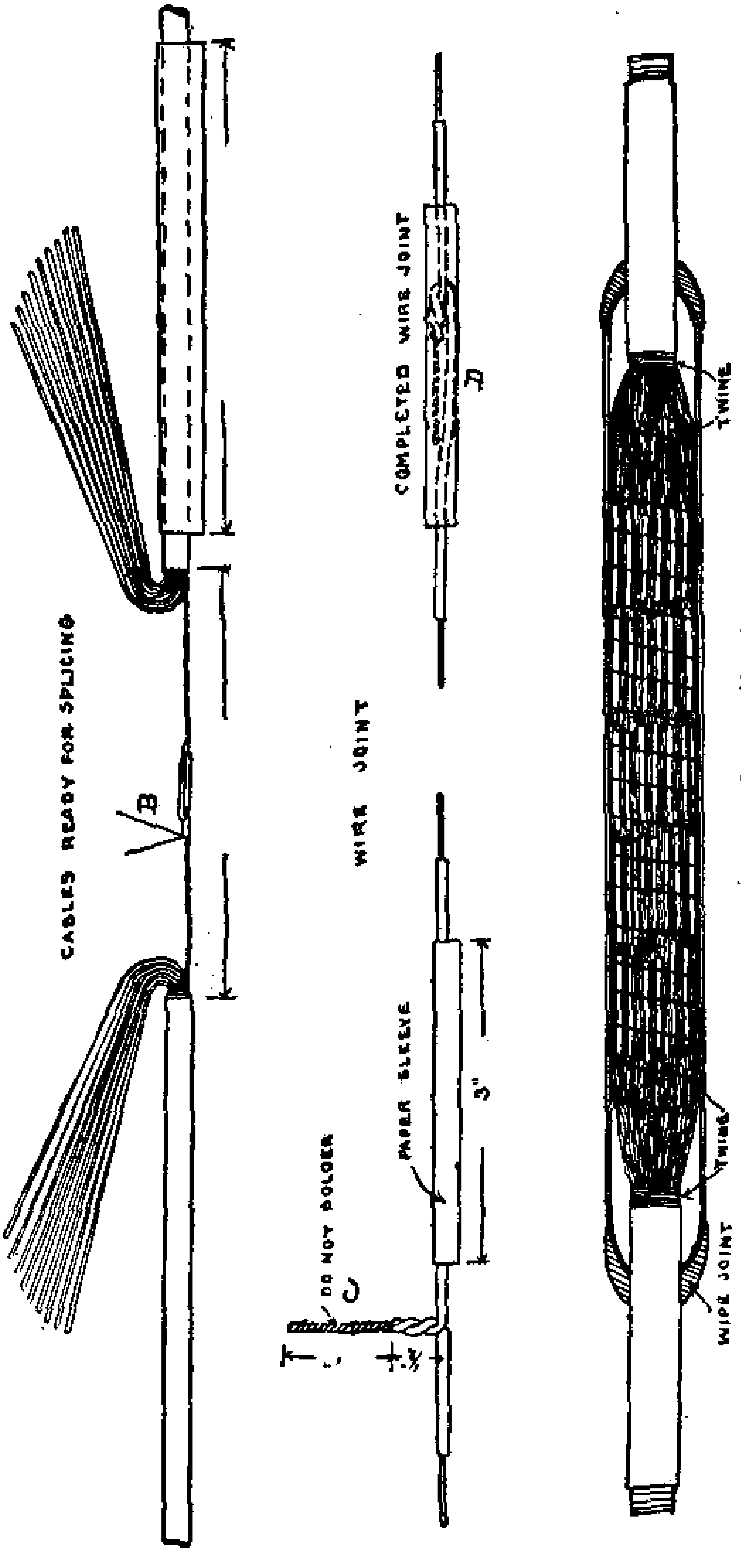


Fig. 43.—Main Cable Splice.

SECTION 40.

Material Required.

Paper Sleeves,

of rolled paper, 3″ long, $\frac{1}{8}$″ diameter, boiled in paraffine, one for each wire to be spliced.

Paraffine.

Best quality, of Standard Oil Company manufacture, free from moisture, acid, or any substance injurious to the cable; a sufficient quantity to fill a pot or pan in which the splice can be completely immersed.

Solder.

Fifty per cent tin, fifty per cent lead; enough to fill a solder pot.

Wicking.

COTTON; one large ball.

Lead Sleeves.

Pure lead. One sleeve for each splice, sizes to be as per Table No. VI.

TABLE No. VI.

Sizes of Lead Sleeves for Main Cable Splices.

	Length, Inches.		Diameter, Inches.		Thickness, Inches.
400 Pair Cable	40	×	4	×	$\frac{3}{16}$
350 " "	38	×	4	×	$\frac{3}{16}$
300 " "	36	×	$3\frac{1}{2}$	×	$\frac{3}{16}$
250 " "	34	×	$3\frac{5}{8}$	×	$\frac{3}{16}$
200 " "	32	×	$3\frac{1}{4}$	×	$\frac{1}{8}$
150 " "	30	×	3	×	$\frac{1}{8}$
120 " "	28	×	$2\frac{3}{4}$	×	$\frac{1}{8}$
100 " "	28	×	$2\frac{1}{2}$	×	$\frac{1}{8}$
50 " "	28	×	2	×	$\frac{3}{32}$
30 " "	26	×	$1\frac{1}{2}$	×	$\frac{3}{32}$
25 " "	25	×	$1\frac{1}{2}$	×	$\frac{3}{32}$
15 " "	24	×	1	×	$\frac{3}{32}$
10 " "	20	×	1	×	$\frac{3}{32}$

While this table gives general dimensions for lead sleeves, they shall always be about $\frac{3}{4}$-inch larger than the sheaths of the cables to be spliced, from $\frac{}{32}$ to $\frac{3}{16}$ inch in thickness, and long enough to allow the splicing of all conductors without producing bunching sufficient to prevent the splice from entering the sleeve, and with sufficient lap to cover each cable sheath at least $1\frac{1}{2}$ inches.

SECTION 41.

Operation.

Remove from 12 to 20 inches of each cable sheath, as shown in Fig. 43, bind the core at the end of each sheath tightly with wicking, packing the binding close tc the end of each sheath, as shown, to prevent paraffine from following the core. Boil out each end by immersing it in melted paraffine, heated to from 225° to 250° F., till all bubbling ceases. Each end shall be immersed so that the cotton binding is thoroughly saturated with paraffine. Slip the lead sleeve over one cable, slip a paper sleeve over each wire in one cable, splice each wire of every pair in one cable to the correspondingly colored wire in a pair in the other cable, by stripping the paper from each wire for a distance of about one inch, and twisting the ends tightly together, as shown at *B* and *C*, Fig. 43. After twisting bend the twist parallel with the wire, slip the paper sleeve over the twist as insulation as at *D*. Care shall be exercised not to nick or injure any wire in removing the paper. Each twist shall include about $\frac{1}{2}$-inch of paper-covered wire. No solder shall be used. The twisted wire joints shall be so distributed that the splice

shall be essentially uniform in diameter throughout its length. When all the wire joints are completed the splice shall be immersed in boiling paraffine for fifteen minutes, or until all bubbling ceases. The lead sleeve shall then be slipped over the splice, so that it may lap the lead of each cable sheath for $1\frac{1}{2}$ to 2 inches. The ends of the sleeve shall then be dressed into close contact with the cable sheath and each end wiped to its respective cable sheath. After the wiping is done the sleeve shall be finally boiled by immersing it in boiling paraffine. A small hole shall be drilled at each end of the sleeve to admit the paraffine and give exit to contained air. These holes shall be drilled along the axis of the cable. When cold the surplus paraffine shall be cleaned off, all wiped joints dressed and the holes soldered up smooth and clean, and the job left in a neat and workmanlike manner. After each splice is completed the cable shall be tested for conductivity and insulation, as specified in A 1, Section 30.

2. BRANCH CABLE SPLICES.

SECTION 42.

General Description.

The method of making splices in paper cables whereby a cable is legged to another cable, or where one cable is branded into two or more other cables, is essentially similar to that described in B 1, specification for Main Cable Splices, and is illustrated in Figs. 44, 45 and 46.

SECTION 43.

Materials.

The materials to be used shall be the same as specified in B 1, Section 40, for the same size of cable. Where necessary split sleeves may be used, as shown at *B*, Fig. 46. If a split sleeve is used the splice must be taped with okonite, and split in the sleeve soldered up air-tight.

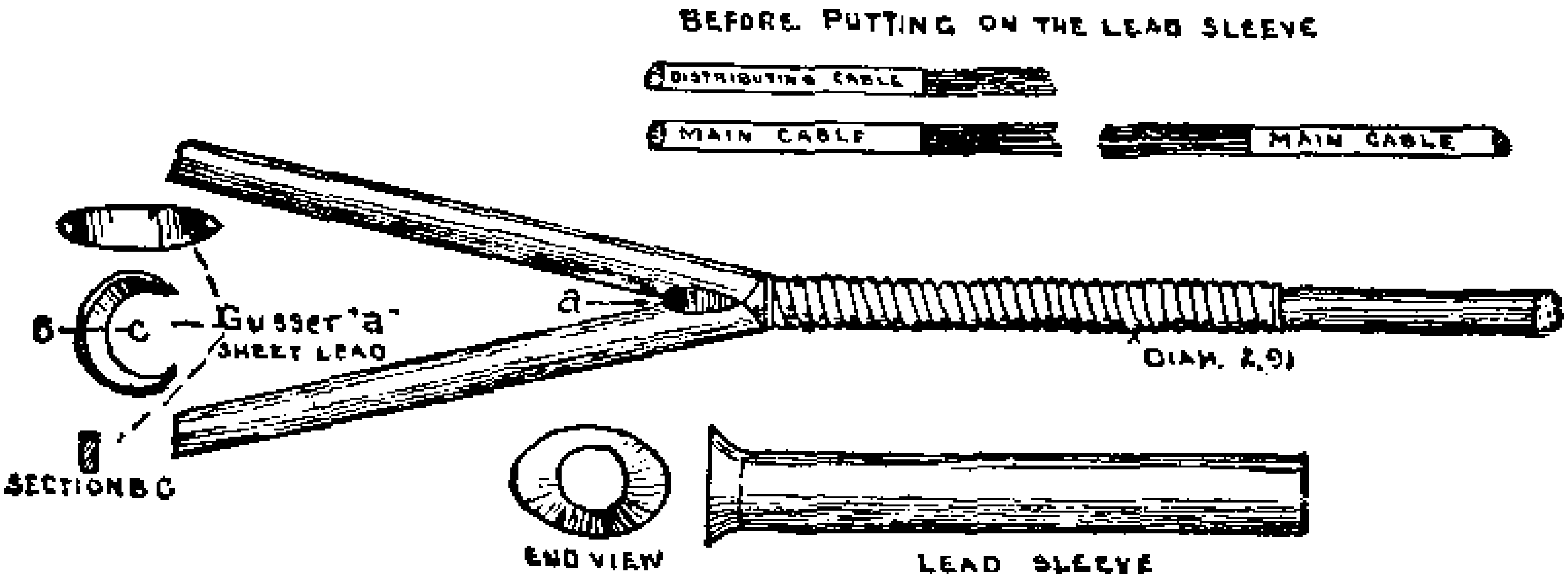


Fig. 44.—Y Splice.

SECTION 44.

Operation Legged Cable.

The method of making legged cable splices shall be exactly the same as that specified for main cable splices in B 1, excepting that each wire of the main cable shall be continuous through the splice into the main cable on both sides of the splice, and each wire of the legged cable shall be spliced on to such a wire of the main cable as is designated for this purpose. All the wires in both the main cable and the branch cable shall be numbered, and the wires in the branch cable shall be spliced to such corre-

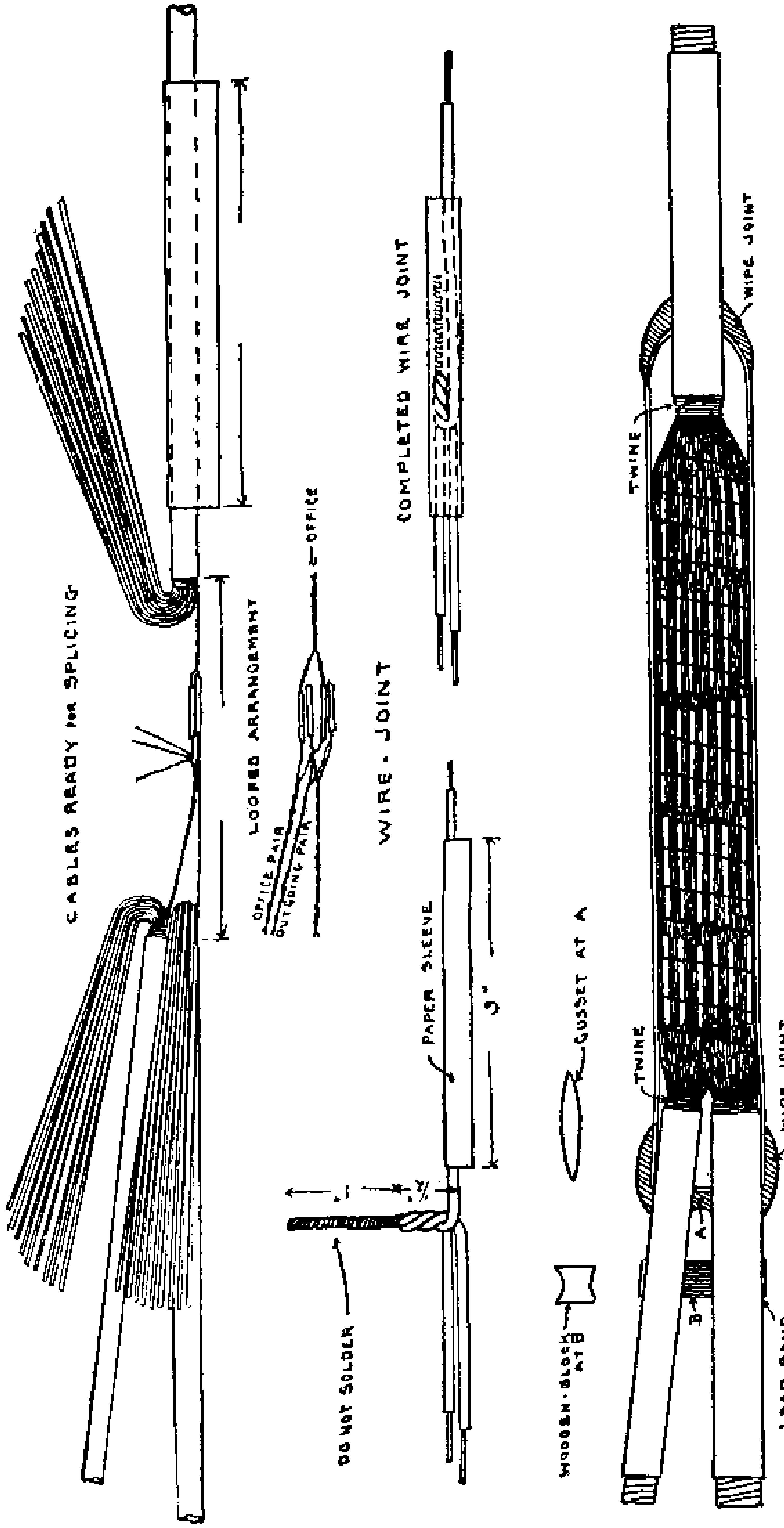


Fig. 45.—Legged Cable Splice.

sponding numbers in the main cable as shall be designated at the time the splice is made. On the completion of the splice all the wires of both the main cable and the branch cable shall be tested completely from one terminal to the other, both for conductivity and for insulation, as specified in A 1, Section 30, and shall fulfill all the tests therein called for.

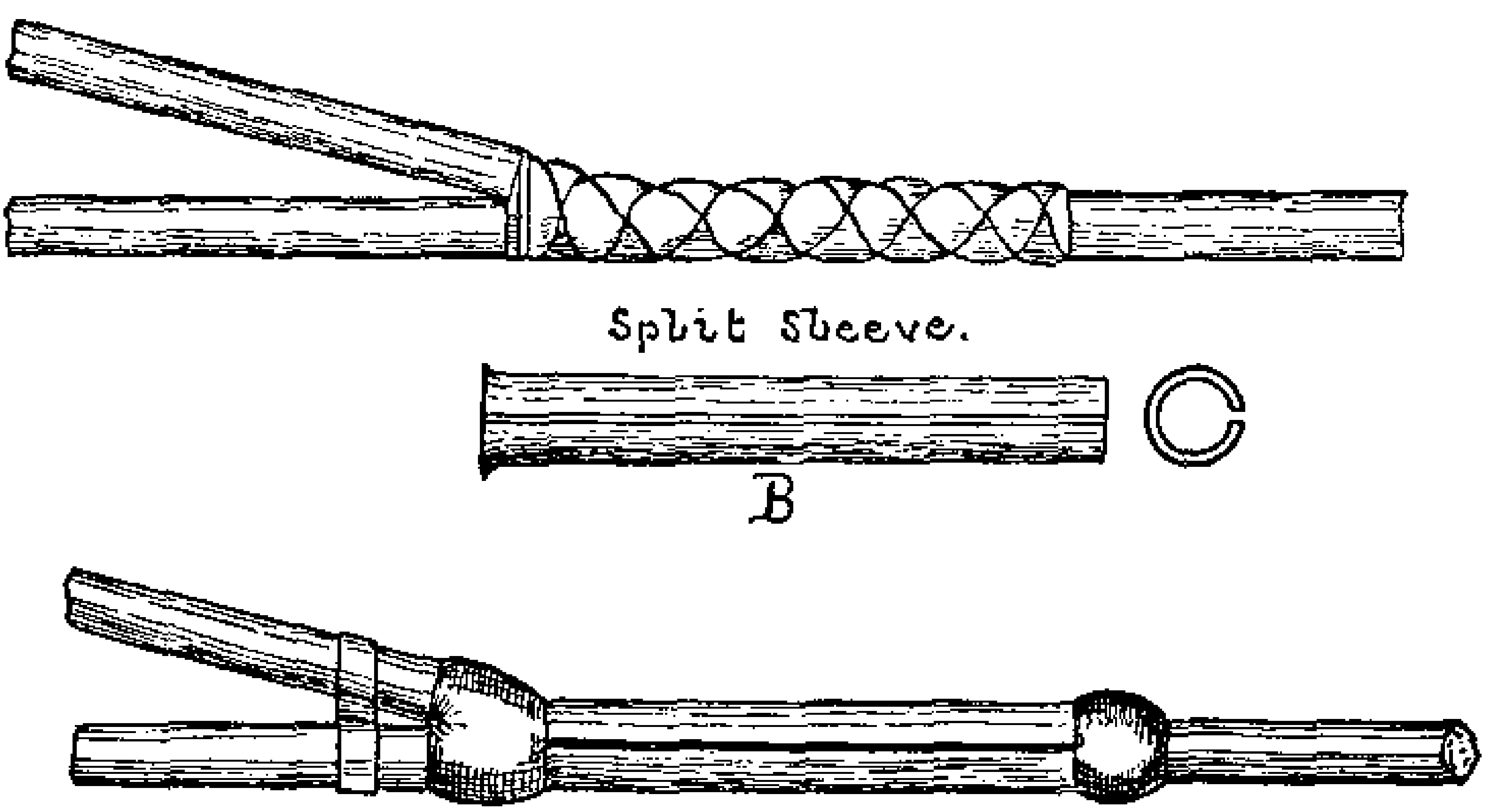


Fig. 46.—Split Sleeve.

SECTION 45.

Operation Branched Cable.

The method of making branched cable splices shall be exactly the same as that specified for legged cable splices in Section 44, excepting that a certain number of wires in the one cable shall be designated to a corresponding number of wires in each branch, and shall be spliced to the branch cable wires, and shall not be continued in any other cable.

(C) SPECIFICATIONS FOR TERMINALS.

1. CABLE HEAD TERMINALS.

SECTION 46.

Supply of Cable Heads.

The cable heads shall be supplied by.......................... and shall be delivered free of expense to........................ at .... Office cable heads shall be of the type known in the trade as the.........................cable head. Pole cable heads of the type known as ....

SECTION 47.

Specification for Heads.

(A) Plain Heads.

1. Each cable head shall be supplied with a brass sleeve of proper size to fit the sheaths of the cable it is intended to terminate. This sleeve shall be strong and substantial, and so fitted to the head as to make a solid and air-tight joint.

2. Each head shall be supplied with as many insulated pins extending from the inside of the head to the outside of the head thereof as there are wires in the cable to which the head is to be attached. These pins shall be so constructed as to maintain an insulation of not less than 1,000 megohms, pin to pin, and pin to ground. They shall be strong and substantial, and so set as to make the interior of the head air-tight. Each pin shall be supplied at each end with a nut, or screw-head, or slot for soldering, or

other means for attaching the cable wire approved by the Company.

3. The space occupied by the cable wire shall be capable of being hermetically sealed in such a manner as to prevent any moisture from reaching the cable, and yet so built that access can be had to the cable with the least amount of work.

(B) Protected Heads.

Protected heads shall fulfill all the specifications of A of this section, and in addition shall be supplied with devices approved by the Company to protect the cable conductors from lightning or from strong currents, or both, as the Company may direct.

1. Lightning Guards.

Lightning guards shall consist of a spark gap composed of a pair of carbon plates separated by an insulating septum of material approved by the Company not over one hundredth of an inch (.01) thick. One plate shall be connected to the line, the other to the ground. The plates shall be held in place by a metal spring or socket, so designated as to permit them to be easily replaced, yet capable of retaining them constantly in good working condition. When any arrester operates it shall permanently ground the line. The lightning arrester shall be placed between the fuse and the cable. There shall be one arrester for each wire.

2. Strong Current Arresters.

Strong current arresters shall consist of a fuse or a "heat coil," as the Company may elect.

(*a*) Fuses for cable heads to be used on line poles shall

be of the "inclosed type," consisting of a lead or lead alloy wire inclosed in an insulated tube. The fuse shall blow at not over seven amperes nor less than five amperes. The fuse gap shall be not less than $2\frac{1}{2}$ inches long. Fuses shall be waterproof and so made that fuse wire is protected from accidental injury, and connected to the cable head substantially, and easily replaceable when blown.

(*b*) Fuses for office heads may be of the type known as "Maxstadt," composed of a fuse wire supported on an insulating base. They shall have a carrying capacity of not over 1.25 amperes nor less than .6 ampere. They shall be so mounted on the head as to be protected from accidental injury, yet easily replaceable.

(*c*) Heat coils shall be so designated as to open the switchboard side of the line and ground the cable side when they operate. Heat coils shall have a carrying capacity of not less than .5 ampere nor more than .75 ampere. Shall be so arranged as to sound an alarm when they operate, wholly and substantially made and easily replaceable.

SECTION 48.

Method of Terminating.

The lead sheath shall be stripped off of the cable for a sufficient distance to allow the end of the sheath to be soldered to the metallic terminal of the cable head and leave such a length of the conductors freed from the sheath as may be sufficient to make the proper wire form to reach each and all of the terminal pins on the interior of the cable head. After the sheath is stripped the core adjacent to the end of the sheathing shall be lashed with

twine or wicking, as specified under B 1, Section 41. The end of the cable shall then be immersed in melted paraffine and boiled until all bubbling ceases, and in such a manner that the paraffine shall penetrate at least 18 inches inside of the cable sheath and hermetically seal it. After the boiling is complete and the cable is cool the end shall be passed into the head. The core of the cable shall then be fanned out and the wires so formed and lashed with waxed twine as to make a proper form to fit the terminal arrangement of the cable head. This form may be made by any method which shall be capable of yielding a neat and workmanlike form, substantially lashed and accurately spaced to match the terminal pins in the head. On the completion of this form the paper insulation shall be stripped off for about one inch on the ends of each wire. The sheath shall then be soldered to the cable head terminal with a wiped joint of solder, half lead and half tin, in such a manner as to make a solid, substantial and absolutely air-tight joint. When this joint is complete the form shall be bent into its proper place inside the cable head and each wire shall be carefully and thoroughly soldered to each terminal pin of the cable head, or otherwise fastened thereto. In making soldered connections no acid or other corrosive soldering flux shall be used. Rosin only shall be employed to make solder flow. After each wire is properly fastened to its appropriate pin the whole form inside the cable head shall be thoroughly shellacked with thick, unstrained shellac varnish, or other approved waterproof coating, a sufficient number of coats being applied to thoroughly cover all the paper of the form and all the wires to and including the terminal pins

inside of the head, with a thick, substantial coat, sufficient to exclude all moisture and to render the form waterproof. The cover of the cable head shall then be put in place and carefully sealed in such manner as to make a moisture-proof joint.

2. FLEXIBLE TERMINALS.

SECTION 49.

Description.

Flexible terminals shall be made by splicing to paper cables a supplementary cable or wire form of such a number of insulated wires as shall correspond to the number of wires in the cable, said supplementary form being composed of insulated wires, protected with some kind of insulation, which shall be moisture-proof and which shall prevent the entrance of moisture to the paper cable. Said supplementary form shall be of such length and so arranged as to reach and match the distributing boards, terminals or other pieces of apparatus to which the cable is to be attached.

SECTION 50.

Okonite Terminals.

The okonite flexible terminal shall consist of a form of okonite twisted pairs sufficient to extend each of the paper cable pairs to their proper terminal pins.

SECTION 51.

Material.

Lead Sleeves to be of unalloyed lead $\frac{1}{8}$-inch thick and of dimensions according to Table VII. of this section. About three-fourths the length of each sleeve should be drifted out of the proper size to cover the splice.

TABLE No. VII.

Approximate Quantities and Dimensions of Materials Required for Different Sizes of Terminals.

Size of Cable.	Lead Sleeves.		Sealing Compound.	Solder.	Rubber Tape.
	Length. Inches.	Inside Diameter Inches.	Pounds.	Pounds.	Pounds.
10	16	$1\frac{5}{8}$	2	$\frac{1}{2}$	$\frac{1}{2}$
25	20	2	$3\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
50	20	$2\frac{1}{2}$	$4\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
100	24	3	$4\frac{1}{2}$	1	$\frac{3}{4}$
150	24	$3\frac{1}{2}$	$6\frac{1}{2}$	1	1
200	28	$3\frac{3}{4}$	$7\frac{1}{2}$	$1\frac{1}{2}$	1
250	30	4	9	$1\frac{1}{2}$	1
300	32	$4\frac{1}{2}$	10	2	$1\frac{1}{2}$
350	34	$4\frac{1}{2}$	13	2	$1\frac{1}{2}$
400	36	$4\frac{3}{4}$	15	2	2

Flexible Terminals. — Twisted pairs of black and red okonite, No. 19 gauge, $\frac{3}{32}$-inch insulation, without braid or other external covering. Each okonite pair shall project beyond the terminal for such a length as may be requisite to reach the terminating point of said pair.

Okonite Tape. — $\frac{3}{4}$-inch wide, 1 roll.

Paper Sleeves. — As per B 1, Section 40.

Brass Tubing. — One piece of thin annealed brass tube ½-inch in diameter, 2½ inches less in length than that of the lead sleeve.

Wicking. — As per B 1, Section 40.

Wiping Solder. — Containing 50 per cent tin, a sufficient quantity.

Sealing Compound. — Sealing compound shall be composed of 10 per cent, by weight, of heavy rosin oil and 90 per cent of D. D. insulating compound. In place of D. D., Chatterton compound or any first-class waterproof rubber semi-elastic cable sealing compound may be used, which, when melted, will readily flow into the sleeve around the okonite wires and firmly adhere to both wire and sleeve. No compound which contains any paraffine derivative or similar substance capable of affecting the rubber of the okonite shall be used.

SECTION 52.

Operation.

Fig. 47 is a detail drawing showing the construction of a flexible terminal. The cable sheath shall be removed for 12 to 24 inches, depending on the size of cable. The cable core shall be thoroughly dried out, *without boiling in paraffine.* Slip lead sleeve over the cable, splice each cable wire to corresponding okonite wires by twisting the ends together and protecting with paper sleeve, as described in Specification B 1, Section 41, joining the colored wire of the cable to the red okonite of each pair. Keep all wire splices within a limit of from 10 to 20 inches from the end of the cable sheath. Remove all bits of

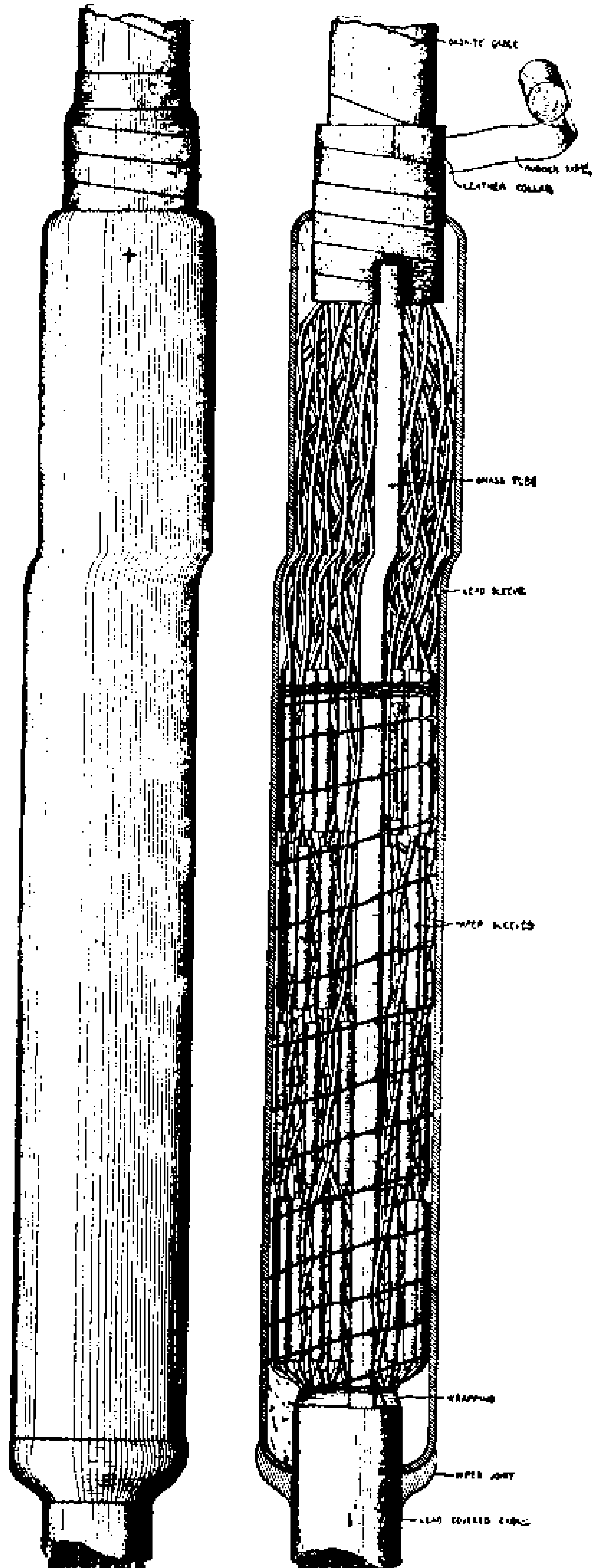


Fig. 47. — Flexible Terminal.

paper or other débris; bind the cable wires at the sheath tightly with several layers of twine to prevent the compound entering the cable. Tape the okonite together tightly for two or three inches, depending upon size of cable, at such a point as will bring the taping at least ½-inch below the subsequent surface of the compound. Below the taping separate the wires to freely allow the compound to flow between them. Bind the brass tubing with twine lightly along the wires with the lower end opposite the end of the cable sheath. No binding twine shall be placed beyond the wire splices. Draw the lead sleeve over the splice until it laps the head of the cable 1½ inches, then wipe the sleeve into place. Place the splice upright, warm the sleeve until it can hardly be touched with the hand. Insert a funnel into the brass tube and pour in compound, previously heated to about 350° F., slowly until it fills the sleeve within ½-inch from the top. Before filling the sleeve, test the compound by immersing therein a piece of okonite wire for about two minutes. If the insulation of the wire is not so softened as to readily come off the compound is not too hot. After filling the sleeve, allow the splice to become thoroughly cold. If any settlement appears refill with compound. If there is no settlement dress the top of the lead into contact with the okonite tape, as shown in Fig. 47. Mark the outside of the sleeve, where the brass tube ends, and cover the end of the thus completed joint with two layers of okonite extending from the first wrapping tape over the edges of the sleeve. *No paraffine or any similar substance shall be used in connection with terminals of rubber-covered wire. Cables must be dried by dry heat.*

SECTION 53.

Distributing Board Terminals.

When terminals are made for distributing boards, to be used in reasonably dry locations, leaded or unleaded switchboard cable, or wool cable, may, at the option of the Company, be substituted for okonite.

SECTION 54.

Unleaded Switchboard Cable.

For this purpose, first-class quality of silk and cotton twenty-pair (20) switchboard cable shall be employed, and a sufficient number of switchboard cables used to match the wires in the paper cable. These cables shall be substituted for the okonite, specified in Section 50, and the pot-head made up exactly in the same manner as if okonite was employed.

SECTION 55.

Lead Covered Switchboard Cable.

If the distance from the pot-heads to the distributing frame is considerable, leaded switchboard cable shall be used to maintain good insulation. The lead sheath of the switchboard cable shall only be removed from the switchboard cable for such a distance as will expose a sufficient length to splice to the wires of the wire plant cable, thus allowing the lead sheath of each switchboard cable to extend not less than four (4) inches inside of the lead sleeve forming the pot-head. When the switchboard

cables are ready to splice to the wire plant cable a round lead disk shall be prepared $\frac{1}{8}$-inch thick, of such a size as to closely fit into the lead sleeve of the pot-head. This disk shall have such a number of holes bored in it as will accommodate the number of switchboard cables to be spliced into the pot-head, the holes being $\frac{1}{64}$-inch larger than outside of the lead of the switchboard cables. This disk shall be then slipped on to the switchboard cables, and the switchboard cables spliced to the wire plant cable. The lead sleeve of the pot-head shall then be slipped into place and wiped on to the lead of the wire plant cable. The sleeve shall then be filled with dried sand, packed and rammed as closely as possible to within two (2) inches of the top of the lead. The lead disk above specified shall then be slipped along the switchboard cables and forced inside of the pot-head sleeve down upon the top of the sand, so as to be about $1\frac{7}{8}$-inches below the top of the pot-head sleeve. The lead of the sleeve, the lead disk and the lead of the switchboard cables shall then be carefully cleaned, and wiping solder shall be poured in on top of the lead disk and around the lead of the switchboard cables so as to make a soldered joint between the sleeve and the lead of the switchboard cables. After the joint has cooled the lead sleeve shall be trimmed off carefully and the whole joint finished in a neat and workmanlike manner.

SECTION 56.

Wool Cable Terminals.

Wire insulated with wool is to a considerable degree non-inflammable and non-hygroscopic, and may be used

to join wire plant cables to distributing boards. Such wool cables shall be joined to the wire plant cables at some point where the splices can be conveniently made. When connected to underground cables the best place is in the office manhole or in the basement run in of building, at the option of the Company. When joined to aerial cables the best place is the horizontal run of cable after entering the building. The length of wool cable for each incoming cable shall not be less than fifteen (15) feet. The wool cable shall be joined to the wire plant cable by means of a splice made according to Specification B 1. The lead covering of the wool cable shall be preserved on that cable up to the point where the first wires must branch away, and at this point the whole core shall be firmly bound with tape.

SECTION 57.

Terminal Forms.

After the flexible cable is spliced to the wire plant cable, irrespective of the kind of material used for the purpose, the flexible end shall be carefully and neatly formed to match the terminal to which it is to be attached. The end of each wire shall be bared for half an inch and securely and substantially attached to the terminal designated by the Company for the purpose. The form shall be securely and neatly lashed in its place to the support provided, and thoroughly shellacked or otherwise waterproofed, if so ordered by the Company. All pot-heads and cable-heads shall be thoroughly secured to the supports provided in a neat and substantial manner

satisfactory to the Company; all cable shall be laid neatly and compactly in the runs provided, and the entire work finished in a neat and workmanlike manner and to the satisfaction of the Company.

SECTION 58.

Supports.

All the necessary racks and supports for holding any and all cable and all terminals shall be provided by..........

(D) SPECIFICATIONS FOR CABLE INSTALLATION.

1. UNDERGROUND CABLES.

SECTION 59.

Preparation of Manhole and Ducts.

The ducts into which the cable is to be installed shall be designated by the Company. When the cable to be installed is delivered, the manholes into which the ducts open shall be cleaned and any cable in them carefully and neatly packed against the walls to give as good access as possible to the ducts into which the new cable is to be placed. Each duct shall then be cleaned by drawing through the duct a steel brush, as specified in *Specifications for Underground Conduit, Section* 26. If a fish wire is already in the duct, it may be used to draw in the proper rope for the brush. If there is no fish wire the duct must be rodded, as described in *Specifications for Underground Conduit, Section* 26. The cable shall not be started into the duct till it is clean and free from obstruc-

tion. The mouth of each duct, while the cable is being drawn in, shall be protected by a shield of leather or guard so arranged as to prevent the edge of the duct from injuring the cable sheath.

SECTION 60.

Attachment of Pull Rope and Drawing.

The pull rope shall be so attached to the cable with a swivel as to distribute the stress of drawing in uniformly over the entire cable without twist in such a manner that neither the sheath nor core shall be strained or injured in the slightest degree. Power for drawing may be supplied in any desired way, either manually or by horse power, or, preferably, with a hoisting engine, as shown in Fig. 48, but it must be sufficient and adequate for the purpose, and completely under control. When the cable has once started it shall be drawn slowly and steadily without stopping at the rate of from five to ten feet per minute, until it is completely in its final place.

SECTION 61.

Arrangement of Reel.

The reel holding the cable shall be carefully transported without unboxing to the manholes at which drawing in is to begin. Here the reel shall be mounted on an axle of such a height as will cause it to clear the street about six inches, and so that it shall easily and freely revolve, as shown in Fig. 49. The reel shall be set close to the manhole, so that the cable can feed directly into the mouth of cover without dragging on the ground.

SECTION 62.

Feeding Cable.

The cable shall be fed into the duct in such a manner as to produce the least strain in pulling, and so as to absolutely avoid all kinks or other injuries to the sheath. As of necessity conduit manholes differ greatly in size, shape, and accessibility, it is impossible to specify exactly the outfit needed for each case; but sufficient rollers, sheaves, guides, or other mechanical appliances or a sufficient force, shall be provided to accomplish the result specified.

SECTION 63.

Splicing.

When the cable is properly drawn into place the ends of the cable shall be coiled down into the manhole, ready for splicing. In case the cable is cut from a longer section, a sufficient amount shall be allowed for splicing, and splicing shall be done immediately, or else the cut ends *shall be boiled in paraffine and hermetically soldered.* The reel, with any remaining cable, shall be carefully reboxed, removed at once from the street and stored.

2. AERIAL CABLE.

SECTION 64.

General Description.

The work of installing aerial cable on existing pole lines may be divided into two parts:

First. The installation of the necessary messenger strands required to support the cable.

Second. The erection of the cable upon the messenger wire ; the termination of the cable at each end by splicing to some other cable, or the installation of a cable head or flexible terminal, set either in the office or in a pole box, with or without balcony.

SECTION 65.

Steel Strands.

All wire used for strands shall be of steel, cylindrical in section, uniform in quality and free from all die marks, scales, sand splits, flaws or other imperfections. Each wire shall be double galvanized and shall fulfill the tests for galvanizing given in *Specifications for Aerial Lines.*

Each strand shall contain not less than seven wires laid up in a neat and uniform manner, showing no loose or imperfect places. The tensile strength of a section containing a wire that is spliced shall be as high as the tensile strength of a section containing no splice.

The properties of strands shall be as Table No. VIII.

SECTION 66.

Installation of Messenger Wire.

Each messenger shall be made of wire rope, as specified in Section 65. The stress to which messengers may be subjected is specified in Table No. IX., and the size of each messenger shall be selected from Table No. VIII., in Section 65, from the column headed "Working Strength." When not more than two cables are to be erected on one line of poles each strand shall be supported by a messenger sup-

TABLE No. VIII.

Tensile Strength of Strands in Pounds.

Diameter.		Bessemer.		Siemens.		High Steel.		Extra High.		Lay of Strand.
Strand.	Wire.	Working.	Ultimate.	Working.	Ultimate.	Working.	Ultimate.	Working.	Ultimate.	
$\frac{1}{4}$ In.	.072	600	2500	762	3050	1275	5100	1900	7600	3 In.
$\frac{5}{16}$ "	.109	1050	4200	1215	4860	2025	8100	3025	12100	$3\frac{1}{2}$ "
$\frac{3}{8}$ "	.120	1425	5700	1700	6800	2875	11500	4312	17250	$3\frac{1}{2}$ "
$\frac{7}{16}$ "	.134	1900	7600	1750	7000	3750	15000	5625	22500	4 "
$\frac{1}{2}$ "	.165	2450	9800	2750	11000	4500	18000	6750	27000	$4\frac{1}{2}$ "

port similar to that shown at *A*, Fig. 50. For each strand one of these supports shall be bolted upon each pole, each about one foot below the lowest cross-arm, and in such a manner that the axis of the groove *B* of the support is perpendicular to the cross-arm. Upon each line of poles the supports shall be bolted relatively on the same side of the pole, so that the messenger may be strung in an essentially straight line. The messenger supports may be placed on the pole in advance, and the strands subsequently drawn in place, or the strands and supports erected simultaneously.

When the messenger supports are properly bolted to the pole the strand shall be erected by drawing it from its reel and placing it in the groove marked *B*, Fig. 50, and clamping it tightly in the support by means of the upper plate and bolts.

SECTION 67.

Angle Iron Cross-Arms.

Wherever more than two cables are to be erected upon one pole line an angle iron cross-arm shall be used. This angle iron cross-arm shall consist of a piece of 3 × 4 inch angle, weighing 30 to 36 pounds per yard, which shall be bolted to the pole in the place of the ordinary cross-arm in the lowest gain. The method of securing this angle iron to the pole and of inserting therein the ordinary wooden cross-arm is fully shown in Fig. 50 at *C*, *D*, and *E*. From this drawing it is seen that the angle iron arm is placed underneath the regular cross-arm, and the whole set in the lowest gain and bolted to the pole in the usual manner as specified for aerial lines. In addition, two 1-inch bolts

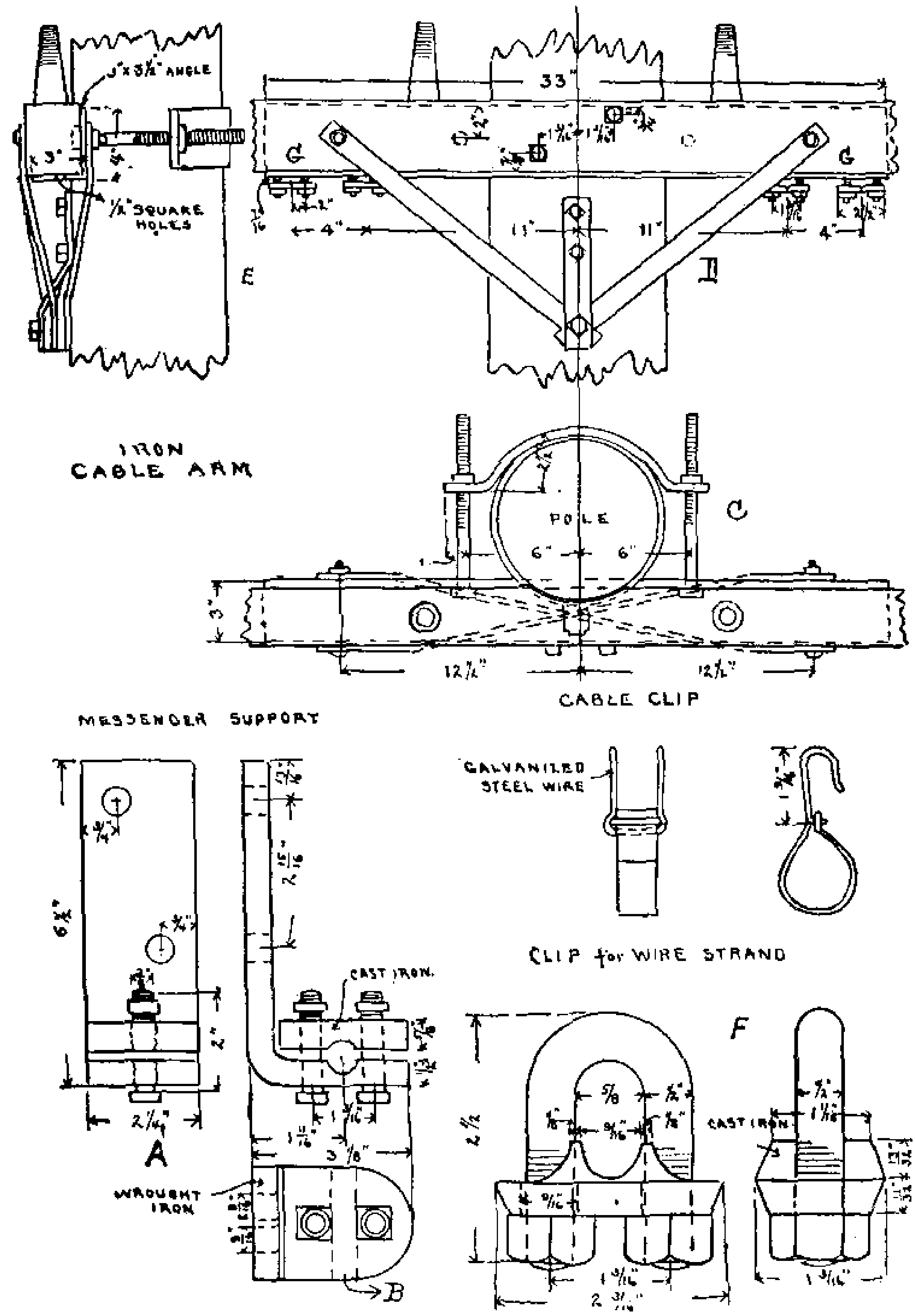


Fig. 50.—Details of Aerial Cables.

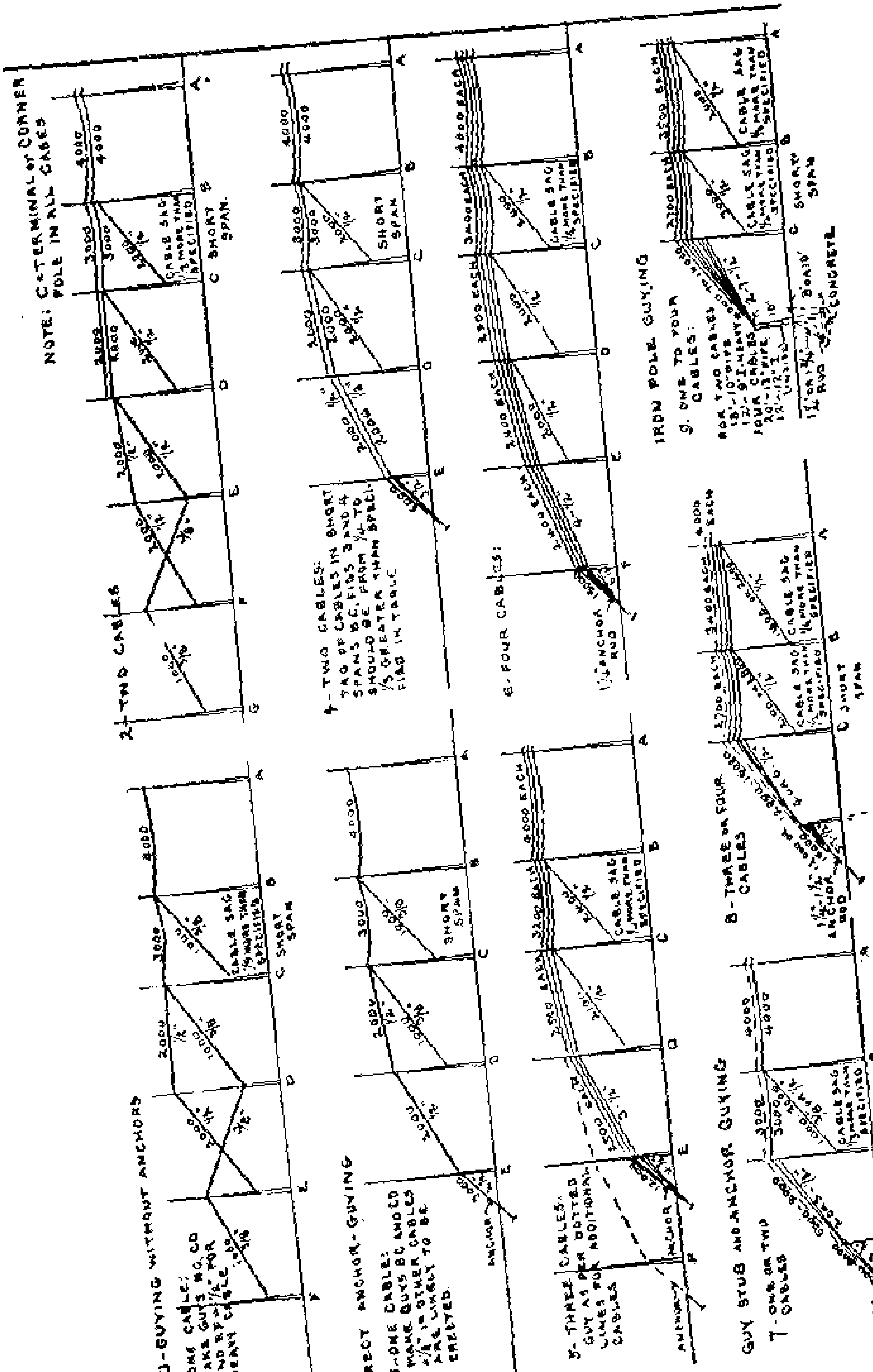


Fig. 51.—Tension for Messengers.

are inserted in the angle iron, over which a band is placed encircling the pole, as shown in Fig. 50 at *C* and *E*. Further, the cross-arm shall be stayed by four cross-arm braces, two on the inside and two outside of the arm. For each cable which the line is to carry, a Standard U-bolt shown at *F*, Fig. 50, shall be placed in the angle iron arm in the manner shown at *G*. Each angle iron cross-arm, when erected, shall be supplied with four standard U-bolts, two on each end of the arm, as shown at *G*. When each messenger wire is erected the lower plate of this U-bolt shall be removed, the messenger inserted between the arms of the U, and the plate replaced and bolted into place.

SECTION 68.

Tension for Messengers.

After each messenger wire is erected in place all of the bolts of the supports, whether U-bolts or standard messenger supports, shall be loosened and the tension of the strand adjusted, so as to bring a uniform strain at all the poles. This shall be accomplished by so loosening all the support fastenings that the strand is free to slide from span to span along the whole length of the pole line. The proper tension to which messenger strands shall be adjusted may be ascertained by the center deflection of the strand at the middle of each span. The proper center deflection to which messengers shall be adjusted for temperatures from 20° below zero, F., to 100° F., and for 80 ft., 100-ft., 120-ft., 150-ft., and 200-ft. spans, and for 50, 100 120 and 150-pair cable is shown in Table No. IX.

TABLE No. IX.

Sag of Cables and Total Tension in Suspension Strands at Different Temperatures.

Temp., F.°.	80-Foot Span. Sag in Inches at Center.	80-Foot Span. Tension in Pounds.	100-Foot Span. Sag in Inches at Center.	100-Foot Span. Tension in Pounds.	120-Foot Span. Sag in Inches at Center.	120-Foot Span. Tension in Pounds.	150-Foot Span. Sag in Inches at Center.	150-Foot Span. Tension in Pounds.	200-Foot Span. Sag in Inches at Center.	200-Foot Span. Tension in Pounds.
50-Pair Cable.										
20	6	4,000	$9\frac{1}{2}$	4,000	$13\frac{1}{2}$	4,000	21	4,000	37	4,000
0	$6\frac{1}{2}$	3,650	10	3,700	$14\frac{1}{2}$	3,700	22	3,750	39	3,800
20	7	3,300	11	3,400	$15\frac{1}{2}$	3,450	$23\frac{1}{2}$	3,500	41	3,600
40	8	3,000	12	3,100	$16\frac{1}{2}$	3,200	25	3,300	43	3,450
60	$8\frac{1}{2}$	2,700	13	2,850	18	2,950	27	3,100	45	3,300
80	$9\frac{1}{2}$	2,450	14	2,600	$19\frac{1}{2}$	2,750	$28\frac{1}{2}$	2,900	47	3,150
100	$10\frac{1}{2}$	2,200	$15\frac{1}{2}$	2,400	21	2,550	30	2,750	49	3,000
100-Pair Cable.										
20	8	4,000	13	4,000	$18\frac{1}{2}$	4,000	$28\frac{1}{2}$	4,000	51	4,000
0	9	3,700	$13\frac{1}{2}$	3,750	$19\frac{1}{2}$	3,800	30	3,800	53	3,900
20	$9\frac{1}{2}$	3,400	$14\frac{1}{2}$	3,500	$20\frac{1}{2}$	3,550	$31\frac{1}{2}$	3,650	$54\frac{1}{2}$	3,750
40	$10\frac{1}{2}$	3,150	$15\frac{1}{2}$	3,250	22	3,350	33	3,500	$56\frac{1}{2}$	3,600
60	11	2,900	$16\frac{1}{2}$	3,050	23	3,200	$34\frac{1}{2}$	3,300	$58\frac{1}{2}$	3,500
80	12	2,700	18	2,850	$24\frac{1}{2}$	3,000	36	3,200	60	3,400
100	13	2,500	19	2,700	26	2,850	$37\frac{1}{2}$	3,050	62	3,300
150-Pair Cable.										
20	9.0	4,000	14.5	4,000	20.5	4,000	31.5	4,000	56.0	4,000
0	10.0	3,700	15.0	3,750	21.5	3,800	33.0	3,800	58.0	3,900
20	10.5	3,400	16.0	3,500	22.5	3,550	34.5	3,650	60.0	3,750
40	11.5	3,150	17.0	3,250	24.0	3,350	36.0	3,500	62.0	3,600
60	12.0	2,900	17.5	3,050	25.5	3,200	38.0	3,300	64.0	3,500
80	13.0	2,700	19.5	2,850	27.0	3,000	39.0	3,200	66.0	3,400
100	14.5	2,500	21.0	2,700	28.5	2,850	41.0	3,050	68.0	3,300

As fast as the messenger wire is adjusted to the proper tension, all fastenings shall be screwed up solidly and substantially so as to hold the messenger firmly in place.

SECTION 69.

Anchoring.

Wherever corners are turned, and at each end of each pole line, particular pains shall be taken to reinforce the line in a solid and substantial manner in order that the adequate strength may be secured to resist the strain introduced by the cables. The various methods that may be used for anchoring are given in detail in *Specifications for Aerial Lines*. Special methods applicable particularly to aerial cable construction are shown in Fig. 51, and each end of the line shall be guyed and anchored substantially in accordance therewith.

SECTION 70.

Erection of Cable.

After the messenger wire is in its place and adjusted to proper sag and the various ends and corners of the lines guyed as hereinbefore specified, the aerial cable shall be erected. The reel carrying the cable shall be carefully transported and set about one span away from the pole upon which the cable is to terminate. The reel shall be mounted upon an axle so that it may freely revolve, and so placed that it is about 6 inches above the ground and carefully unboxed. From the terminal pole to the reel a $\frac{3}{8}$-inch or $\frac{1}{2}$-inch guide wire strand shall be erected, serv-

ing to carry the cable from the reel to the terminal pole. At the terminal pole a large wooden sheave shall be placed immediately below the messenger over which the cable shall run. A sufficient length of rope shall be provided, supported on pulleys at each pole, to extend from the pulling apparatus, which shall be located beyond the other terminal pole, along the entire length of the span to the reel, so that the cable may be pulled into place at one operation. Power for pulling the cable may be supplied in any desired manner, either by a capstan operated by manual or horsepower, or preferably a small hoisting engine (see Fig. 48). Whatever apparatus is used it shall be fully under control and capable of pulling the cable uniformly and steadily, after it is started, at the rate of from 10 to 20 feet per minute. The pulling rope shall be carried over the wooden sheave before specified down to the reel and attached to the cable by means of a swivel in such a manner as to distribute the pulling strain uniformly over the core and sheath of the cable, so that neither may be in any wise injured as the cable is drawn along.

SECTION 71.

Cable Supports.

Such cable clips shall be used as shall be approved by the Company, and sufficient hangers shall be employed, so that one may be placed every two feet throughout the entire length of each piece of cable. Actual erection of the cable shall be accomplished by placing one man at the reel to control the unwinding of the cable, and sufficient force between the reel and the first pole to place upon the

cable the hereinbefore specified hangers, and to hook the same upon the guide wires; two men upon the first pole to guide cable over the guide sheave, and one man on each pole to unhook and hook hangers as the cable passes the messenger supports, and a sufficient force at the pulling engine to operate that portion of the apparatus. After drawing is commenced it shall proceed uniformly and steadily until the entire length of cable is erected. When the cable is in its place on the messenger wire a man shall be sent over the line to adjust all hooks in their proper position; he shall see that the hooks are properly attached to both the messenger wire and the cable, and are so secured as to be safe against unhooking. When the attachment to the messenger wire as above specified is accomplished the tension on the cable and on the messenger wire shall, if necessary, be readjusted until it corresponds to the specifications of Table No. IX.

SECTION 72.

Method of Terminating.

Three methods shall be used for terminating aerial cable.

1st. Connection to underground cable. Where aerial cable is to connect with an underground cable, the underground conduit, by means of an iron pipe 3 inches in diameter, shall be extended alongside of the terminal pole for a distance of at least 10 feet above the sidewalk. Either the aerial cable or the underground cable, as the Company may elect, shall be extended through this pipe. In case the Company shall elect to extend the underground cable, the splice between the aerial and the underground

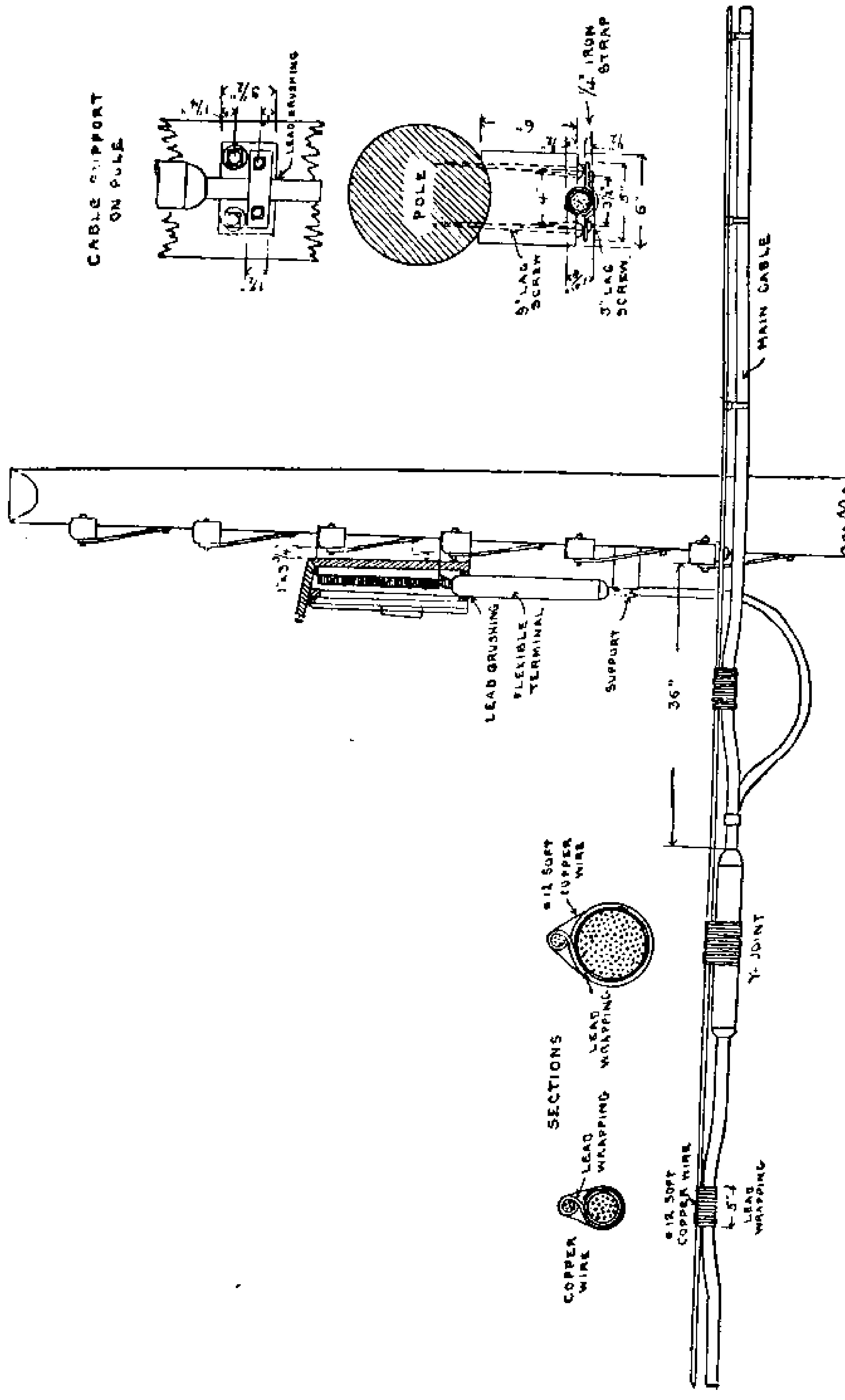


Fig. 52.—Cable Connection to Open Wire

cable shall be made directly above the iron pipe extending along the pole. This splice shall be made as specified in B 1. In case the Company shall elect to extend the aerial cable into the manhole, the cable shall be run downwards through the iron pipe into the manhole, and the splice between the underground and aerial made in the manhole, as specified in B 1.

SECTION 73.

Connections to Open Wire Lines.

At each point where the aerial cable shall terminate and enter an open wire line, a proper box and balcony shall be supplied and bolted to the pole, as shown in Fig. 8. The box and balcony shall be of such design as is approved by the Company, and shall be supplied by .... and shall be erected in place substantially, shown in Fig. 52 by.............................. The cable terminal shall be either a cable head, as specified in C 1, or a flexible terminal, as specified in C 2, as the Company may elect. After the cable is terminated it shall be secured to the pole and brought into the pole box as shown in Fig. 52. In all cases pains shall be taken to carry the cable to the pole with a long, round, easy bend, and in such a manner as not to kink, injure or hurt the cable in any way. A lead bushing shall be inserted in the base of the box through which the cable shall enter. All flexible terminals to aerial lines shall be made of okonite wire, as specified in C 2. The okonite shall be carefully formed, neatly lashed, and carefully secured to the back of the box, each wire being carried to its proper

terminal and there soldered. If the cable head is to be used the cable shall be terminated in the head as specified in C 1. After the cable is spliced into the head, the head shall be placed in the box and bolted to the back thereof. After the cable is erected in place and terminated, it shall be inspected, as provided for in A 1. The Inspector shall test each wire from the terminal point at which the bridle wire is to be attached, and to the other terminal of the cable wherever this may be situated, and each wire must fulfill each and all of the requirements specified under A 1.

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